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NAVAL CONSTRUCTION

—ROBINSON

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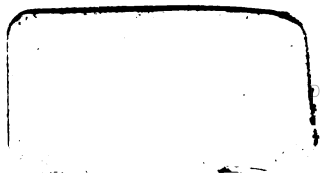

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NAVAL CONSTRUCTION

PREPARED FOR THE USE OF THE

MIDSHIPMEN

OF THE

UNITED STATES NAVAL ACADEMY

BY

R. H. M. ROBINSON

Naval Constructor, U. S. N.

ANNAPOLIS, MD.
THE UNITED STATES NAVAL INSTITUTE
1906

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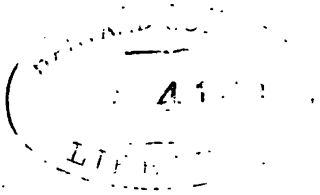

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PREFACE

This book has been prepared at the request of the head of the Department of Marine Engineering and Naval Construction at the U. S. Naval Academy, to provide a modern text-book in the course of Naval Architecture for Midshipmen of the first class. It has been prepared with a view to the special requirements of that Institution, and as it presupposes the preliminary training in mensuration and mathematics that a Midshipman of the first class must have, a considerable portion of the matter usually found in elementary works on this subject has been omitted from the part devoted to calculations.

The part devoted to practical construction has been prepared with a view to furnishing only such information as would be desirable to a line officer, and is in no sense intended as a complete treatise.

Should the student desire to pursue any of the subjects further, a number of references are given at the end of each chapter to works and articles treating of the subject of the chapter.

In the chapter on *Building, Launching,* and *Docking,* no attempt has been made to give other than general knowledge of the methods employed.

The entire book, being intended for officers of the U. S. Navy, has been based upon the practice of that service.

Several subjects within the province of the naval constructor in the U. S. Naval Service have been omitted in order to prevent duplicating the Midshipmen's course of study, as the author is informed that these subjects are treated in other branches of the Department of Marine Engineering and Naval Construction.

The Department having approved the use of such official drawings as were applicable, I am indebted to Rear-Admiral W. L. Capps, U. S. N., Chief Constructor of the Navy, for access to the files of the Bureau of Construction and Repair, to Naval Con-

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structor J. H. Linnard, U. S. N., for assistance on the Stability Chapter, and to Messrs. L. Prior, W. M. Wallace, P. B. Brill, and H. W. Thayer, of the Bureau's drafting force, for their assistance in selecting and putting in suitable form the illustrations.

R. H. M. ROBINSON,
Washington, D. C.

June, 1906.

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Plates having general application to the work:

PLATE I. Sheer draft.
II. Displacement curve.
III. Midship section.
IV. Inboard profile.
V. Main deck and berth deck plans.

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CHAPTER I.

HISTORICAL.

Up to well into the nineteenth century, wood was practically the only material used for shipbuilding. Owing to the increase in the size of ships, made possible by the introduction of steam, wood became unsuitable because of the stresses to which the longer and larger ships are subjected. Wood had the advantage of ease of manipulation and ease with which excessive fouling was prevented, as copper could be attached directly to the hull. The local strength and stiffness of the structure of a wooden ship was great, but the strength of the structure as a whole was less than is possible with metal construction.

A few examples of iron shipbuilding are on record during the latter part of the eighteenth century, mostly applied to canal boats and barges. The first iron steamboat of which there is definite record was the *Aaron Manby,* built in 1820. The first iron warship in our service was the *U. S. S. Wolverine* (formerly the *Michigan*), still in commission on the Great Lakes.

As the size of merchant and passenger steamers increased more rapidly than the size of warships, the introduction of metal into shipbuilding for merchant purpose was, consequently, quicker than in the naval service. In our service, experience in the Civil War with the construction of the *Monitor* and other vessels of this type, served to furnish an impetus for iron shipbuilding for naval purposes, and while up to 1880 a number of wooden ships were still built, iron was in the preponderance for such new construction as was undertaken.

Our present modern Navy dates from the early 80's, the use of steel as a material for construction of hulls being first adopted for the *Dolphin, Boston, Atlanta,* and *Chicago,* laid down in 1883. The transition from iron to steel, beginning not long before these

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vessels were laid down, permitted of somewhat lighter scantling than iron, and consequent decrease of the dead weight of hull and corresponding increase in the power to carry weight for propulsive and for offensive and defensive purposes. The improvement in the methods of manufacture of steel since that date has permitted of many improvements in the systems of framing and attachment. It was early found that iron and steel vessels required unusual care in the preservation of the hull, iron and steel immersed in sea water being subject to rapid corrosion. The British service has built a number of steel vessels sheathed with wood so that they may be coppered. We have in our service several composite gunboats, *i. e.*, steel frames with wood planking instead of plating, but only one class (*Denver* class) of six ships sheathed and coppered. The British and other foreign services seem to be working away from the practice of building sheathed ships, which are more expensive in first cost, and less speedy.

With an unsheathed ship, up to the present time, the only method of preventing the fouling by marine growth is by docking and painting at reasonable intervals. This will be treated of in a later chapter of this book.

The change in the types of ships has also been very marked. In the old days of the wooden sailing line-of-battle ship, the battery was so arranged that the fire was nearly all broadside. The present day battleship embodies some of the essential features of Ericsson's *Monitor* in the form of center-line turrets which permit of end-on as well as broadside fire. The intermediate battery, when carried in the United States service, is generally mounted in redoubts or casemates arranged essentially for broadside fire; but in some foreign services nearly the entire installation is made in turrets.

In our service the freeboard has undergone many changes. The old frigates and line-of-battle ships were high-sided, from which type we jumped to the monitor, and have, in our heavy fighting ships, gradually worked back until we again have high-sided ships. The elevated gun positions give advantages in permitting the use of guns in a seaway, the high freeboard gives greater range of

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stability, and the whole structure is a better gun platform than the low-freeboard ships; it, however, offers a greater target.

The introduction of shell fire made it necessary to provide means for excluding the missiles, which led to the adoption of armor, at first made of laminated plates, later of wrought iron, then of compound, then of nickel steel, then Harveyized, and now the Krupp and other similar processes.

The first British ironclad ship was an iron ship—the *Warrior*. In our service, the *Monitor* was of iron, but the Confederate ram, *Virginia,* was the old wooden U. S. frigate *Merrimac,* razed and plated with railroad iron and boiler plates.

There has likewise been a marked increase in the size of vessels of the United States Service since the beginning of the modern Navy. The following tabular comparison of the principal characteristics of first-class ships of various parts of this period, beginning with the *Boston,* down to the present day, selecting types of each date, is given for the information of the students, as indicating the increase in size, armament and cost of first-rate men-of-war in the U. S. Service:

Name.	Type.	Building date.	Length.	Breadth	Draft.	Displacement.	Armament.	Speed.	Contract price.
			ft. *in.*	*ft.* *in.*	*ft.* *in.*			*knots.*	
Chicago (Original)	Protected Cruiser	1883-87	315 0	48 2	19 0	4,500	4 8″ 8 6″ 2 5″	15.3	$889,000
Columbia	Protected Cruiser	1890-94	411 7	58 2	22 6	7,350	1 8″ 2 6″ 8 4″ 19 small	22.8	2,725,000
Brooklyn	Armored Cruiser	1893-96	400 6	64 8	24 0	9,215	8 8″ 12 5″ 23 small	21.9	2,986,000
Indiana	Battleship	1890-95	348 0	69 3	24 0	10,288	4 13″ 8 8″ 4 6″ 29 small	15.5	3,063,600
Maine	Battleship	1899-02	388 0	72 2	23 10	12,500	4 12″ 16 6″ 24 small	18.0	2,885,000
Connecticut	Battleship	1902-06	450 0	76 10	24 6	16,000	4 12″ 8 8″ 12 7″ 50 small	18.0	4,212,000

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REFERENCES FOR MORE COMPLETE STUDY IF DESIRED:

Warships and Navies of the World, King.
Ancient and Modern Ships, Holmes.
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Navies of the World, Very.
Brassey's Naval Annuals.
Transactions Society of Naval Architects and Marine Engineers.
Proceedings Institute of Naval Architects.

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CHAPTER II.

DEFINITIONS.

The Sheer Draft (see Plate I) is a line drawing of a ship's form including the following:

The sheer plan, a longitudinal elevation or side view of the ship; it is usually arranged with the bow towards the right and the stern towards the left; on it are shown the boundary lines of the ship, viz., the keel, contour of the stem and stern, the rail and different deck lines at the side, the waterlines, the bow and buttock lines, and the diagonal lines and cross section stations.

The half-breadth plan, representing the horizontal plan of one side of the ship, which is sufficient, as both sides are symmetrical; in it appear the forms of the various waterlines, rail and deck lines at the side, the cross section stations, and the bow and buttock lines and development of diagonals.

The body plan, consisting of a pair of half transverse elevations or end views of the ship, both having the same vertical middle line, so that the right-hand side represents the ship as seen from ahead, and the left-hand side as seen from astern. Both sides of the ship being symmetrical, it is required only to draw one side. On the body plan appear the forms of the various cross sections, the curvature of the rail and deck lines at the side, the waterlines, bow and buttock lines, and the diagonal lines.

In two of the plans, viz., the sheer plan and body plan, the waterlines appear as straight horizontal lines, while in the half-breadth plan their curvature or form is shown. Their endings in the half-breadth plan are obtained from their intersection with the stem, stern post, and stern in the sheer plan.

In large vessels, the waterlines are generally spaced two feet apart, commencing from, and running parallel with, the load waterline, while in small vessels the distance between them is reduced. Waterlines are generally designated in the different plans by their

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distance from the base line, viz., 4 feet, 8 feet, or 12 feet waterline, etc., commencing with the one nearest to the keel.

The cross sections appear as straight vertical lines in the sheer plan and half-breadth plan; in the former they stand perpendicular to the waterlines, and in the latter, perpendicular to the center line. In these two plans, the distance apart of frames, measured from molding edge to molding edge, called the frame space, is sometimes shown.

In the body plan the contour or form of the cross sections is shown, but not their distance apart. The largest of the cross sections, or rather the widest at the load waterline, situated generally at or near the middle of length of the ship, is called the *midship section* or *dead flat,* and is marked with the symbol ⋈ on the plans. While in the body plan all the other cross sections appear only on one side of the vertical center line, the forward ones on the right and the after ones on the left, the midship section ⋈ is shown on both sides.

The midship section divides the ship into two parts, called respectively the *fore-body* and the *after-body.* Sometimes there is a part of the ship, at or near the middle, which has a uniform cross-section throughout its length, its waterlines being parallel to the center line; this, when it exists, is called the *middle-body,* or sometimes the *parallel middle-body.*

To enable the same cross section stations to be readily found on the different plans, they are marked with numbers in their order from bow to stern.

The three plans are closely connected inasmuch as all the principal lines are shown in each of them. The ordinates of either one are repeated on, or transferred to, at last one of the other plans, which is also the case with the intersections of any two sets of lines. Thus, all the ordinates of any waterline, taken from the half-breadth plan, are found on the corresponding waterline of the body plan; and all the waterline ordinates which define the form of a frame or cross-section are found on the corresponding frame or cross-section in the half-breadth plan.

All intersections of bow and buttock lines with the waterlines and rail or deck lines in the half-breadth plan, and with the cross-

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sections or frames in the body plan, are transferred to their corresponding waterlines and cross-sections or frames in the sheer plan, thus giving the points which define the curve of the bow and buttock lines in that plan.

The sheer plan shows position of all ordinates, but not their length. The half-breadth plan shows their lengths and positions lengthwise, but not vertically. The body plan shows their lengths and positions vertically, but not lengthwise.

The lengths of ordinates and their positions being shown in any two plans, sufficient data are given to show the figure of the ship completely; but the three plans together give the mind a more distinct idea of that figure and are more convenient for purposes of measurement and calculation.

Any two of the plans being given, the third may be constructed therefrom.

Waterlines are lines which the surface of the water forms with the side of a vessel at various successive depths of immersion parallel to the load waterline or base line; they appear straight in the sheer plan and body plan, while their curvature or form is shown in the half-breadth plan.

Deck lines are the lines representing the form of the deck in the half-breadth plan; in the body plan and sheer plan they are represented by the curves passing through the intersection of the deck heights with the side of the ship.

Deck lines at side are the lines showing the fore and aft curvature of the deck at side in the sheer plan, and the excess of the freeboard at bow and stern over that amidship. In the body plan they are represented by the curve passing through the intersection of the deck heights with the side of the ship.

Bow and buttock lines are formed by longitudinal vertical sections or planes parallel to the longitudinal vertical central plane which divides the ship into two symmetrical halves. In connection with the waterlines, they are of great service in regulating or fairing the bow and stern, and in connection with the cross-sections or frames, are valuable to fair up the ship's bottom, as will be treated of later. In the body and half-breadth plan they appear as straight lines, while in the sheer plan their form or curvature is shown.

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Diagonal lines are represented in the body plan by straight lines crossing the waterlines obliquely. They are of special use for regulating the bottom and bilge and laying down and fairing up, as they intersect the outer surface of the ship at nearly right angles. In the sheer plain they are generally shown at the extremities for the purpose of fairing in connection with the bow and buttock lines. As seen in the diagonal plan, they make the ship appear of greater width than she really is, on account of their oblique direction.

The sheer of a vessel is the longitudinal curve of the rail, decks, etc., which shows the difference of height above water, or freeboard, at the stem and stern over that amidships.

Sheer lines appear in the body and sheer plan, and are simply required to determine the upper ending or head of the frames, or to mark the height of the deck beams at side. The height of the rail or decks is taken on each cross section from the sheer plan and is transferred to the body plan. Lines parallel to the waterlines are struck in through the points so transferred, and on these plans the respective half-breadth of the rail or deck line, taken from the half-breadth plan, is set off.

Base line.—This is to the naval architect the line from which all vertical dimensions and heights are measured. In the U. S. Service, for ships designed without a "drag," it is a line coincident with the bottom of the keel. In foreign services it is generally coincident with the top of keel. For a ship with a "drag," it is a line parallel to the waterlines and tangent to the keel contour line at the dead flat.

Forward perpendicular is a line perpendicular to the keel line and intersecting the forward side of the stem at the designed load waterline. This is known as F. P.

After perpendicular is a line perpendicular to the keel line, drawn tangent to the after contour of the stern. This is known as A. P.

Mid perpendicular is a line perpendicular to the keel line and taken midway between the forward perpendicular and the after perpendicular. This is known as M. P.

Length between perpendiculars is the dimension used by naval architects in connection with the design of ships; it is measured

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from the forward perpendicular, or F. P., to the after perpendicular, or A. P.

Length over all is the length measured from a line perpendicular to the base line and tangent to the forward side of the stem, to a

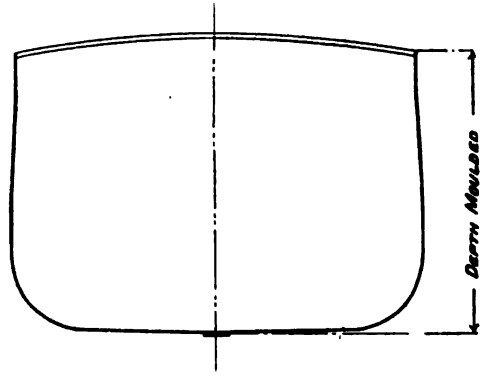

FIG. 1.

line perpendicular to the base line and tangent to the after end of the stern.

Moulded breadth is the width of the widest frame at its outside and is therefore a dimension taken inside of all shell plating.

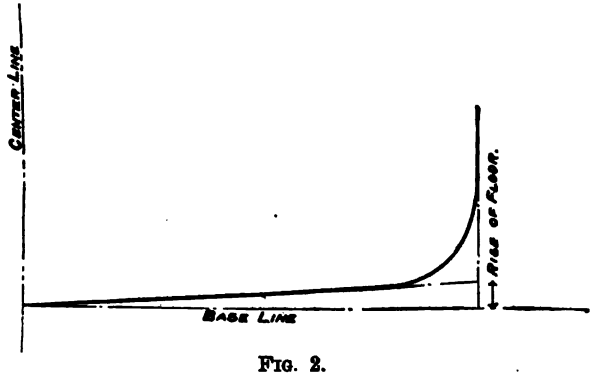

FIG. 2.

Breadth extreme is width over outside of shell plating or armor plating at widest frame.

Depth moulded is the depth from the top of the keel to the top of the main deck beam at side.

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Rise of floor is the amount a tangent to the outside of the midship frame, starting at the intersection of center line with base line, rises above the horizontal in the half breadth of the ship.

Camber or round up is the curvature, convex toward top, given to deck beams to add to the arch strength of the structure and insure proper drainage of decks.

Draft is the depth from waterline to bottom of keel when a vessel is afloat.

Draft aft is that measured at the stern.

Draft forward is that measured at the bow.

Mean draft is the average between that measured at bow and at stern, or that measured at middle of length.

Light draft is that at light displacement.

Load draft is that at load displacement.

Draft extreme is that measured to the lowest projecting portion of the vessel.

Trim is the difference in draft at bow of a vessel from that at the stern.

Drag is the designed excess in draft aft over that forward. This is little used in modern warships, though often found in yachts and other sailing craft.

The following extract from the regulations governing the location of draft marks in the U. S. Service is quoted:

"Draft marks are to be in Arabic numerals, and for numbers greater than 10, the last figure only of the number is to be used. Draft marks are to be cast or cut out of sheet metal and secured by screws. Where they come upon metal parts, and for metal vessels, the positions of the draft marks are to be accurately located by punch marks or light scores.

"Draft marks, when vertical, are to be 6 inches high, the even foot indicated being at the bottom of the mark; when not vertical they are to be of such height that their projection upon a vertical plane is 6 inches high.

"In every case there is to be one set of draft marks as far forward as practicable, and a second set as far aft as practicable, each set consisting of a line of marks on each side. Each line of marks should be as nearly as possible vertical when the vessel

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is at her normal trim, but minor variations, in order to follow contours of stem and stern post, may be made when desirable, especially at some distance above or below the normal waterline. For the forward and after marks in vessels of ordinary form, the drafts are to be measured in a direction perpendicular to the load waterline from a draft line which coincides with the straight line of the bottom of the keel.

"In the case of vessels that are so much cut up aft that the after marks indicate a draft of water materially greater than the actual maximum draft, a third set of marks is to be placed abreast of the lowest point of the keel.

"In the case of vessels with rocker keels, the draft line from which the forward and after draft marks are set up is to be a tangent to the keel at the lowest point parallel to the normal waterline. In this case a third set of marks should be placed abreast the lowest point of the keel.

"Draft marks for torpedo-boats will be laid off in accordance with the foregoing rules, except when a skeg aft, or the rudder, or tip of propeller blades projects below a draft line fixed by the preceding directions; in such cases, the draft line is to be drawn from the lowest point of the skeg, rudder, or tip of propeller, tangent to the bottom of the keel."

Displacement.—The amount of water displaced by any floating body is called its *displacement*. In the case of ships it is generally expressed in tons; one ton of sea water being equal to 35 cubic feet, and one ton of fresh water to 36 cubic feet.

The displacement of any floating body is equal to the weight of that body, and consequently the displacement of a ship is equal to the weight of the ship with everything on board.

Center of buoyancy is the center of gravity of the immersed volume of the displacement.

Center of gravity is the resultant point at which the weight of all the individual items of the ship's weights may be considered to be concentrated.

Metacenter.—If a ship be inclined to a small angle and a perpendicular be drawn to the load water-plane in the inclined position through the center of buoyancy in the inclined position, this per-

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pendicular will intersect in some point a similar perpendicular drawn through the center of buoyancy in the upright position to the load water-plane in this upright position. This point of intersection M is the *metacenter*.

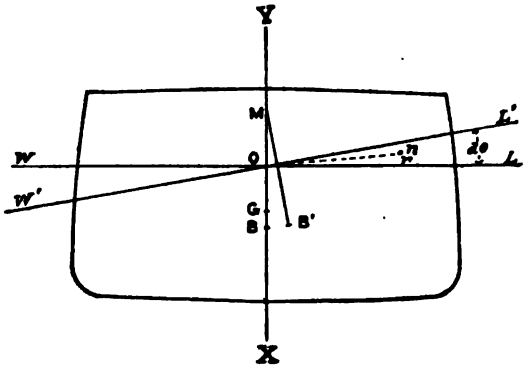

FIG. 3.

Block coefficient is the ratio which the immersed volume bears to the circumscribing rectangular solid, *i. e.*, is equal to

$$\frac{\text{displacement (in tons)} \times 35}{l \times b \times d}.$$

Where l = length between perpendiculars, b = extreme beam, d = mean draft.

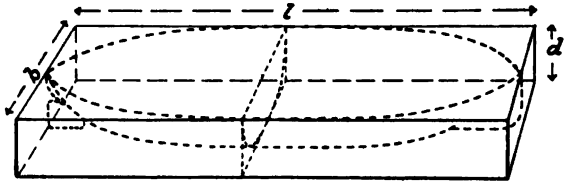

FIG. 4.

Prismatic coefficient is the ratio which the immersed volume bears to the volume of a cylinder whose length is equal to the length

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(B. P.) and whose base is in area equal to the area of the midship section

$$\frac{\text{displacement (in tons)} \times 35}{\text{Area } \mathbb{M} \times L}.$$

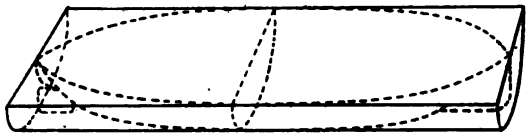

FIG. 5.

Coefficient of fineness of midship section is the ratio which the actual area of midship section below load waterline bears to the rectangle whose breadth equals breadth of this midship section and height equals draft, *i. e.*, the circumscribing rectangle

$$= \frac{\text{Area midship section}}{b \times d}.$$

Coefficient of fineness of water-plane is the ratio which the area of any water-plane bears to the circumscribing rectangle.

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Manual of Laying Off, Watson.
Theorie du Navire, Pollard & Dudebout.

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CHAPTER III.

CALCULATIONS.

In addition to the usual drawing instruments such as the midshipman is familiar with from his course in drawing, *i. e.*, the compass, divider, bow-pen, beam compass, T-square, triangle, and scales, the instruments usually found in a ship drawing office comprise:

Proportional divider, for transferring reduced or enlarged dimensions.

Planimeter, for calculating areas.

Integrator, for getting moment of inertia of any area.

Comptometer and other mechanical devices for adding, subtracting, multiplying, etc.; some of these being self-recording.

Slide rule, both of straight and Fuller type, for making computations.

Apparatus for making blue-prints either by sunlight or artificial light.

In ship drawing it is customary to make only pencil drawings on paper, the finished drawing being in the form of an ink tracing on tracing cloth, from which blue-prints can be made.

Most of the areas to be calculated in shipbuilding are bounded on one or more sides by curves. These curves are or are very nearly parabolas of either the 1st, 2d, or 3d order. It is therefore usual to calculate the areas by means of one of Simpson's rules or by the trapezoidal rule. These rules are as follows:

Simpson's first rule.

$$A = \frac{h}{3}(y_1 + 4y_2 + 2y_3 + 4y_4 \ldots . 4y_n + y_{n+1}).$$

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To find the area of figure, as *ABCD* (Fig. 6).

Divide base into any convenient *even* number of equal spaces and erect ordinates. *The sum of end ordinates plus four times sum of even ordinates and two times sum of odd ordinates, multiplied by one-third the distance between ordinates, equals area.* (For proof, see Johnson's Integral Calculus, Art. 168, p. 195.)

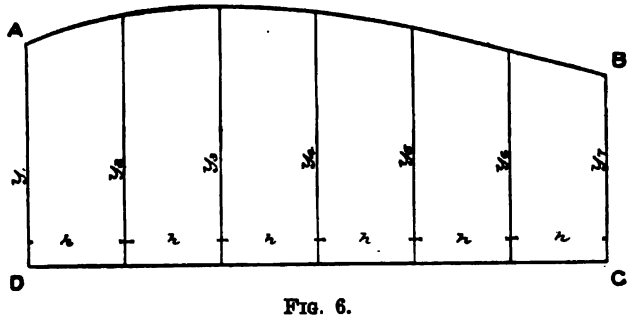

FIG. 6.

EXAMPLE.—A curvilinear area has ordinates 2 feet apart whose lengths are 1.55, 2.75, 4.45, 6.55, 8.60, 10.50, and 11.95 feet: to find area.

Number of Ordinates.	Length of Ordinate.	Simpson's Multipliers.	Function of Ordinates.
1	1.55	1	1.55
2	2.75	4	11.00
3	4.45	2	8.90
4	6.55	4	26.20
5	8.60	2	17.20
6	10.50	4	42.00
7	11.95	1	11.95
			118.80

Common interval = 2 feet.

$\frac{1}{3}$ Common interval = $\frac{2}{3}$ foot.

Area = $118.8 \times \frac{2}{3} = \frac{237.6}{3} = 79.2$ square feet.

Or Simpson's second rule.

NOTE.—In using this rule the number of intervals may be either odd or even.

$$A = \frac{3h}{8}(y_1 + 3y_2 + 3y_3 + 2y_4 + 3y_5 \ldots . 3y_n + y_{n+1}).$$

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The sum of end ordinates plus two times sum of ordinates numbers 4, 7, 10, etc., plus three times sum of all other ordinates, multiplied by $\frac{3}{8}$ distance between ordinates, equals area. (For proof, see Johnson's Integral Calculus, Art. 169, p. 195.)

A curvilinear area has ordinates at a common distance of 2 feet whose lengths are 1.55, 2.75, 4.45, 6.55, 8.60, 10.50, and 11.95. To find area:

Number of Ordinates.	Length of Ordinate.	Simpson's Multipliers.	Functions of Ordinates.
1	1.55	1	1.55
2	2.75	3	8.25
3	4.45	3	13.35
4	6.55	2	13.10
5	8.60	3	25.80
6	10.50	3	31.50
7	11.95	1	11.95
		Sum of functions	105.50

Common interval = 2 feet.

$\frac{3}{8}$ Common interval = $\frac{3}{4}$ foot.

$105.5 \times \frac{3}{4} = \frac{316.5}{4} = 79.125$ square feet.

When the curvature of a line forming boundary of an area is sharp, intermediate ordinates must be used, the spacing of the

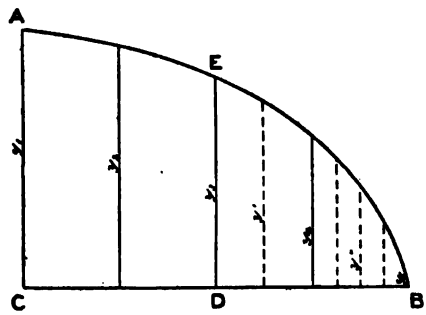

FIG. 7.

intermediate ordinates being a submultiple of the ordinary spacing.

Area *DEB* (Fig. 7) $= \frac{1}{3}\left(\frac{h}{2}\right)(y_3 + 4y' + 2y_4 + 4y'' + y_5)$

where $y_5 = 0$.

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The 5-8 rule, applicable to curvilinear area contained between two consecutive ordinates is as follows:

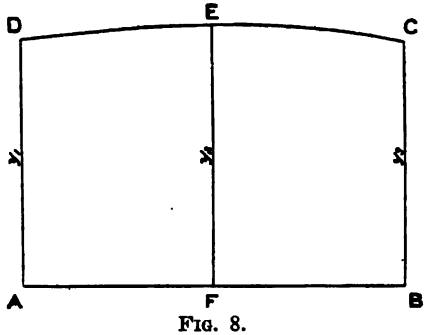

FIG. 8.

$$\text{Area } ADEF \text{ (Fig. 8)} = \frac{h}{12}(5y_1 + 8y_2 - y_3).$$

Eight times middle ordinate plus five times near end ordinate minus far end ordinate multiplied by 1/12 interval, equals area between first two ordinates.

Trapezoidal rule.—This rule is generally used by the Bureau of Construction and Repair of the U. S. Navy, in its calculations, but

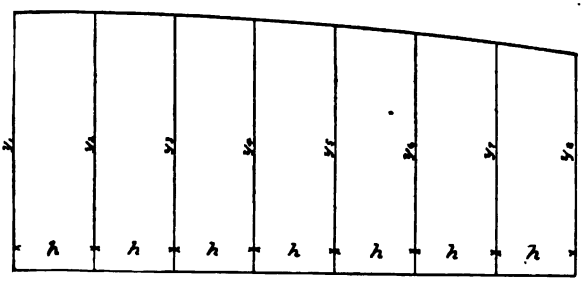

FIG. 9.

requires special care in spacing and measuring the ordinates. (See Fig. 9.)

$$A = h\,(\tfrac{1}{2}y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7 + \tfrac{1}{2}y_8),$$

or

Divide base into *any* convenient number of equal spaces and erect ordinates meeting the curve.

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Sum of one-half the end ordinates plus sum of all other ordinates, multiplied by common interval, equals area.

This rule is based on assuming that each part of the area bounded by consecutive ordinates is a trapezoid, and the area of a trapezoid = height $\times$ $\frac{1}{2}$ sum of bases, as the midshipman has learned in his geometry.

In the case of actual ship calculations, if we compute by one of the rules above the areas of the various equidistant waterlines, beginning with the keel, and use these values as ordinates, we may plot a curve from which the area of any waterline, at any draft, may be taken as desired. Such a curve appears on the displacement scale (Plate II).

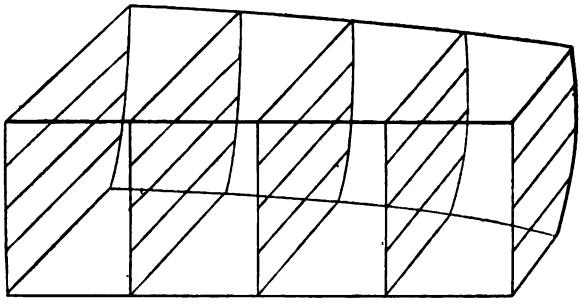

FIG. 10.

Volume of solid bounded by curved surface.—This is an ordinary requirement in ship calculations, as in finding volumes of coal bunkers and other compartments—the most important case being the underwater volumes of the ships.

In this case the volume is generally considered divided by a number of parallel planes equally spaced, as shown in sketch. (Fig. 10.) The area of these planes is then determined by one of the above rules, and the results taken as ordinates of a curve of areas, the ordinates having the spacing of the parallel planes. This curve may actually be drawn, as is sometimes desirable to check the fairness, and the area of curves then calculated as before, giving the volume; or the calculation may be made without

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actually drawing the curve, as is generally done in the displacement calculation, to save time and space.

EXAMPLE.—The underwater portion of a vessel is divided by vertical sections 10 feet apart and these sections have the following areas: 0.4, 22.8, 48.9, 73.3, 88.5, 82.9, 58.8, 26.3, 4.0 square feet. To find volume:

Number of Section.	Area of Section.	Simpson's Multipliers.	Functions of Areas.
1	0.4	1	0.4
2	22.8	4	91.2
3	48.9	2	97.8
4	73.3	4	293.2
5	88.5	2	177.0
6	82.9	4	331.6
7	58.8	2	117.6
8	26.3	4	105.2
9	4	1	4
		Sum of functions	1218.0

$\frac{1}{3}$ Common interval $= \frac{10}{3}$

$\therefore$ volume $= 1218 \times \frac{10}{3} = \frac{12180}{3} = 4060$ cubic feet.

Displacement calculations.—As the underwater body of a ship is symmetrical about the fore and aft middle line plane, only one side is generally used.

The volume is divided, 1st, by equidistant planes parallel to the L. W. plane; 2d, by equidistant planes perpendicular to L. W. plane and to fore and aft middle line plane.

The area of these planes is calculated, and from them the volume. The volume calculated either way should be the same, and the two results are used to check each other. The full details of this calculation as applied to ships, are made on special ruled forms for compactness and ready recording, and while presenting no difficulties are somewhat long and involved, and are not given here. They may be found if desired in detail in "Instructions for Standard Ship Calculations," issued by Bureau C. & R.

Displacement curve.—From dimensions obtained from the sheer draft, the volume of displacement to each of the consecutive water-

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lines is calculated by one of the foregoing rules (in the U. S. Service, trapezoidal rule), and the displacements so obtained are set up on a certain scale above a base line, each at a distance from an origin representing the draft of the water-plane to which the displacement is calculated. This gives a series of spots through which a curve may be run, and from this curve, the displacement at any given draft may be obtained.

In practice, instead of making separate calculations to each waterline, the whole calculation is combined into one, saving time and space.

For curves of displacement, see Plate II.

When the ship is floating at a waterline not parallel to the designed load waterline, and it is desired to obtain the draft, it is customary to read draft aft and forward, take mean, and find displacement from curve corresponding to this mean draft; but the reading obtained from applying the mean draft to the curve is not exactly correct and requires to be corrected for a certain difference of draft forward and aft. In practice, this is done by means of curve of "Additional displacement for one foot change of trim by stern," shown on displacement scale whose deduction is complicated and therefore not given. (It may be found, if desired, on page 14 of "Instructions for Standard Ship Calculations," issued by the Bureau of Construction and Repair).

Displacement in fresh water.—This only varies from that in salt water in that the displacement in tons is determined from the volume by dividing by 36 instead of 35.

A ship whose volume of underwater hull is 4060 cubic feet would have a displacement in salt water of $4060 \div 35 = 116$ tons.

If this ship's underwater volume in fresh water were 4060 cubic feet, her displacement would be $4060 \div 36 = 112.77$.

In actual ship calculations certain projecting portions of the hull fall outside the fair line of hull. These are called *appendages*, are separately calculated and added to the general result to obtain the total.

Curve of tons per inch immersion.—This is a curve, representing at various drafts, the tons (in salt water) of displacement per inch of depth of hull at that draft.

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If A = area in square feet of water-plane at any draft,

$A \times \frac{1}{12}$ = volume in cubic feet of layer 1 inch thick at that draft;

$A \times \frac{1}{12} \times \frac{1}{35}$ = displacement in tons in salt water of this volume;

Or tons per inch immersion at any draft = $\frac{A}{420}$ where A is area of waterline at that draft.

This is calculated for the various waterlines and plotted in form of a curve from which the tons per inch at any desired draft may be obtained.

Curves of areas of midship section.—The area of the midship section up to each of the waterlines is calculated from ordinates

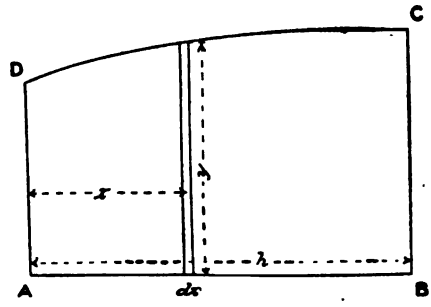

FIG. 11.

measured from sheer draft, and the results obtained are plotted as a curve, which should be a fair curve.

Moment and C. G. of area.—The geometrical moment of an area about a given axis is the product of the area into the perpendicular distance of C. G. from the axis. Therefore, if we know the moment of an area about an axis, and the area, we can find the distance of the C. G. from the axis.

(The student has had this treated of in Johnson's Integral Calculus, Arts. 178-179, pp. 205-206.)

Consider Fig. 11.

Area infinitesimal strip = ydx;

Moment about AD of this strip = $y \times dx \times x$.

Moment whole area about $AD = \int_o^h y \times dx \times x$.

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But the expression for area $= \int_o^h y dx$.

Therefore, C. G. from $AD = \dfrac{\int_o^h y \times dx \times x}{\int_o^h y dx}$.

The practical calculation expression for $\int_o^h y\ dx$ is, as we have seen above, Simpson's rules or the trapezoidal rule, and the practical calculation expression for $\int_o^h y \times dx \times x$ will be seen from the following example:

A load water-plane has the following semi-ordinates: 0, 10.2, 20.0, 27.4, 32.1, 34.0, 33.8, 31.7, 27.6, 20.6, 9.4. The ship is 395 feet long. To find area and position of C. G. relative to middle ordinate:

Number of Ordinate.	Length of Ordinate.	Simpson's Multipliers.	Functions of Ordinates.	No. of Interval from Mid. Ord.	Products for Moments.
1	0.0	1	0.0	5	0.0
2	10.2	4	40.8	4	163.2
3	20.0	2	40.0	3	120.0
4	27.4	4	109.6	2	219.2
5	32.1	2	64.2	1	64.2
6	34.0	4	136.0	0	566.6
7	33.8	2	67.6	1	67.6
8	31.7	4	126.8	2	253.6
9	27.6	2	55.2	3	165.6
10	20.6	4	82.4	4	329.6
11	9.4	1	9.4	5	47.0
			732.0		863.4

Common interval $= \frac{395}{10} = 39.5$ feet.

$\therefore$ Half area $= \frac{39.5}{5} \times 732. = 9638$ square ft.

C. G. from the middle ordinate is $\dfrac{(863.4 - 566.6)}{732} \times 39.5$ or 16.01.

Note C. G. is obtained by working with functions and thus saving time.

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It should be noted in all cases of calculations that the tables are so arranged as to prevent useless duplication of work, the multiplications being made at the end, and due cognizance being taken of cancellations.

To find position of C. G. of an area bounded on one side by a curved line, contained between two consecutive end ordinates, with respect to near end ordinate:

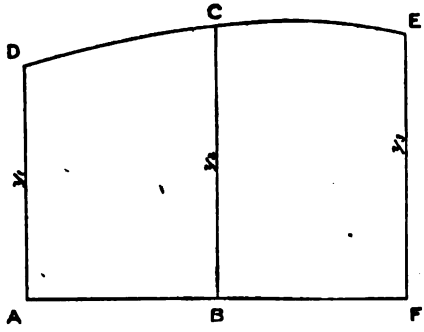

FIG. 12.

Moment of $ABCD$ (Fig. 12) about $AD = \frac{h^2}{24}(3y_1 + 10y_2 - y_3)$.

The curved line being considered as a parabola of the second order.

EXAMPLE.—A curve has ordinates 11, 10, 8 feet long, common interval 4 feet. Find position of C. G. of portion between first two ordinates with respect to near end ordinate.

	Areas.		Moments.	
Ordinates.	Simpson's Multipliers.	Functions.	Simpson's Multipliers.	Functions.
11	5	55	3	33
10	8	80	10	100
8	−1	−8	−1	−8
		127		125

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$$\text{Moment} = 125 \times \frac{(4)^3}{24}$$

$$\text{Area} = 127 \times \frac{4}{12}$$

$$\therefore \text{ C. G.} = \frac{125 \times \cancel{16} \times \cancel{12}}{127 \times \cancel{4} \times \cancel{24}} = \frac{250}{127} = 1.968 \text{ feet.}$$

Position of C. G. of curvilinear area with respect to its base:

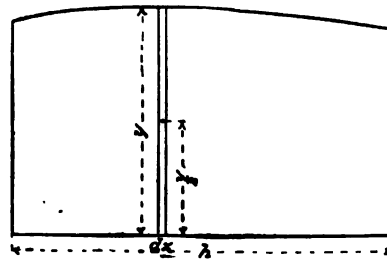

FIG. 13.

(See Fig. 13.)

$$\text{Area} = \int_o^h y\,dx$$

$$\text{Moment about base} = \int_o^h \frac{y}{2} \cdot y\,dx = \tfrac{1}{2}\int_o^h y^2 dx.$$

The practical calculation method of doing this is to apply Simpson's or trapezoidal rule to y^2, *i. e.*, to the square of the measured ordinates.

Having determined the longitudinal location of the C. G. of the various equidistant water-planes, their positions may be plotted to a suitable scale and a fair curve drawn through the spots which represents the locus of the positions of C. G. of water-planes and from which the location of the C. G. of any water-plane may be determined. Such a curve appears in the displacement scale, Plate II.

To find center of gravity of solid bounded by curved surface and plane.—From above we know that in finding the volume of a solid we use the usual rules as in finding area of a plane, except that

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as ordinates we use areas instead of linear dimensions. In a similar manner, the principle used in finding the C. G. of an area applied to this problem, using areas instead of linear dimensions, will permit us to find the C. G. of a solid body.

EXAMPLE.—A coal bunker has sections 17′ 6″ apart and the areas of the sections are 99, 124, 138, 136, 123 square feet.

To find the volume of the bunker and the location of its C. G. relative to the end:

Area.	Simpson's Multiplier.	Functions of Areas.	Number of Interval from End.	Products for Moments.
99	1	99	0	0
124	4	496	1	496
138	2	276	2	552
136	4	544	3	1632
123	1	123	4	492
		1538		3172

$$\text{Volume} = 1538 \times \tfrac{1}{3} \times \tfrac{35}{2} = 8971.66.$$

$$\text{Moment} = 3172 \times \tfrac{1}{3} \times \tfrac{35}{2} \times \tfrac{35}{2}.$$

$$\therefore \text{Dist. C. G. from end} = \tfrac{3172}{1538} \times \tfrac{35}{2} = 36.09 \text{ feet.}$$

In making all calculations of this character, an approximate checking will insure against grievous mistakes. For illustration:

Considering the above bunker we see it to be $4 \times 17\frac{1}{2}$ feet long. An examination of the sections shows it to be fuller at the far end than at the near end, which would indicate that the C. G. would be a little more than half the distance from the near end, which agrees closely with our result.

Calculation of position of C. B.—We have seen this point defined, and it is dependent solely on the form of the underwater portion of the ship. It is therefore evident that the determination of its location is the same general problem as that illustrated in the preceding paragraph.

As a ship is symmetrical about the longitudinal center-line plane, the C. B. evidently lies in that plane. It therefore remains to determine its position:

(1) Above base.

(2) Relative to fore and aft length.

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To find C. B. in fore and aft direction having given areas of equidistant transverse sections.—The underwater portion of a vessel is divided by transverse sections 10 feet apart of the following areas: 0.3, 22.8, 48.9, 73.3, 88.5, 82.9, 58.8, 26.3, 4.0 square feet. Find the position of the C. B. relative to middle section:

Number of Station.	Area.	Simpson's Multiplier.	Function of Area.	Number of Interval from Middle.	Product for Moments.
1	0.3	1	0.3	4	1.2
2	22.8	4	91.2	3	273.6
3	48.9	2	97.8	2	195.6
4	73.3	4	293.2	1	293.2
5	88.5	2	177.0	0	763.6
6	82.9	4	331.6	1	331.6
7	58.8	2	117.6	2	235.2
8	26.3	4	105.2	3	315.6
9	4.	1	4.	4	16.
			1217.9		898.4

$$\text{Volume} = 1217.9 \times \frac{10}{3}$$

Excess products aft $= 898.4 - 763.6 = 134.8$.

$$\text{Moment aft} = 134.8 \times \frac{10}{3} \times 10.$$

$$\text{C. B. aft} = \frac{134.8}{1217.9} \times \frac{10}{3} \times 10 \times \frac{3}{10} = 1.106 + \text{feet.}$$

To calculate C. B. in vertical direction.—Same principle may be used, taking areas of waterlines instead of sections.

To find C. B. in vertical direction.—Area of displacement curve to any waterline divided by the displacement to that waterline = distance of C. B. below that waterline.

AeB (Fig. 14) = curve of displacement.

If area of water-plane at $ge = A$ and z = distance of this water-plane below load waterline,

The volume between water-planes ge and g^1e^1 infinitely close together $= A\,dz$, or its moment about load waterline $= Az\,dz$.

As this is a curve of displacement,

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$g^1e^1 - ge$ = difference of displacement between these two waterlines, or $= \frac{A\ dz}{35}$.

If we draw el and e^1l^1 the strip el^1 is in width $= \frac{A \times dz}{35}$ and area $= \frac{Az\ dz}{35}$.

(1) The area of the curve will be $= \int \frac{Az\ dz}{35}$.

Now moment of volume about load waterline is $\int Adz \times z$ and

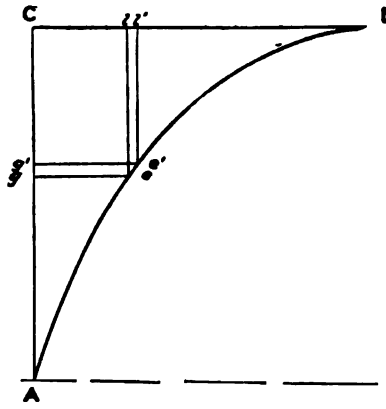

FIG. 14.

the distance C. B. below load waterline is $\int \frac{Az\ dz}{C\ B\ (\text{load draft}) \times 35}$.

From (1) now the area of curve divided by load draft is

$$\int \frac{Az\ dz}{C\ B \times 35},$$

the same thing.

Having seen the method of calculating the position of center of buoyancy or C. B. it remains to be seen how these are plotted on the curves.

The longitudinal position of C. B. is calculated to the various waterlines with reference to some chosen section, and its position plotted from the vertical reference line. (See Plate II.)

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The vertical position of C. B. is calculated for the volumes to the various waterlines with reference to that waterline.

The spots found are then plotted thus: (Fig. 15.)

Through origin is drawn a line OL at 45° intersecting the various waterlines. Where this line intersects the waterlines, the distance of C. B. below that waterline is set down, giving spots as $B_1B_2B_2B_2$ through which a curve can be passed.

Therefore, to find vertical position of C. B., run across the waterline at which it is desired until the 45° line is met, then measure down for the distance of C. B. below waterline at this draft.

We have seen above how the curves of displacement, locus of

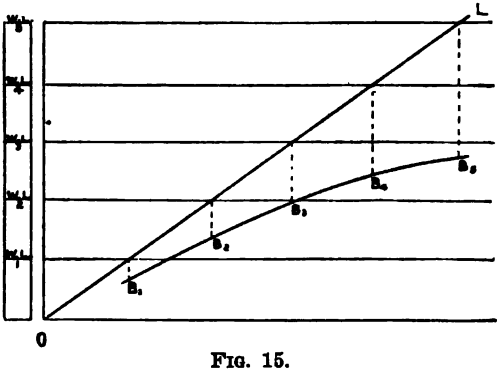

FIG. 15.

center of buoyancy, areas of water-planes, &c., are calculated and plotted.

For actual ships, after having made the calculations, all of which are combined into one general form, the results of these calculations are plotted to form a *displacement scale*. This displacement scale shows the following curves: See Plate II.

1. Displacement in salt water.
2. Displacement in fresh water.
3. Vertical position of center of buoyancy.
4. Longitudinal position of center of buoyancy.
5. Total area of water-planes.
6. Longitudinal position of C. G. of waterlines.
7. Tons per inch immersion.

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8. Whole area of midship section.
9. Transverse metacenter above center of buoyancy.
10. Moment to trim ship one inch.
11. Additional displacement for 1 foot change of trim by stern.
12. Area of wetted surface.
13. Outline of midship section.

Difference in draft of water when floating in sea water and when floating in river water.—The weight per cubic foot of sea water is greater than that of fresh water, hence a vessel on passing from river to sea water, the weight remaining constant, will rise in the water and have a greater freeboard.

Sea water weighs 64 lbs. per cubic foot.

Fresh water weights 63 lbs. per cubic foot.

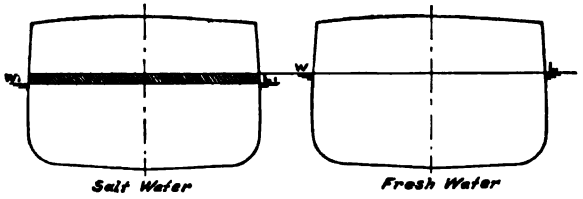

FIG. 16.

Consider Fig. 16.

W = weight of ship in tons.

T = tons per inch immersion at W^1L^1 in salt water.

x = difference in draft between waterlines in salt and fresh water.

In fresh water $\frac{W \times 2240}{63}$ = volume displacement.

In sea water $\frac{W \times 2240}{64}$ = volume displacement.

Volume layer $= \frac{W \times 2240}{63} - \frac{W \times 2240}{64} = \frac{W \times 2240}{63 \times 64}$.

Now volume layer $= x \times T \times \frac{2240}{64}$.

$$x \times T \times \frac{2240}{64} = \frac{W \times 2240}{63 \times 64}$$

$$x = \frac{W}{63\,T} \text{ inches.}$$

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Sinkage caused by bilging a central compartment.—If we take a simple case of a box-shaped vessel having watertight bulkheads at *EG* and *HF* and consider a hole made below the waterline—as in Fig. 17.

If the weight of the ship is $= W$

The displacement must $= W$.

This buoyancy must be the same after bilging as before, and the lost buoyancy must be made up by the vessel sinking in the water until the original buoyancy is again reached.

If W^1L^1 be the new waterline, d^1 the new draft, then as it is rectangular, $WL \times b$ (or breadth) $\times d = W^1L^1 \times b \times d^1 - NO \times b \times d^1$

Or $WL \times b \times d = d^1 \times b\ (W^1L^1 - NO)$.

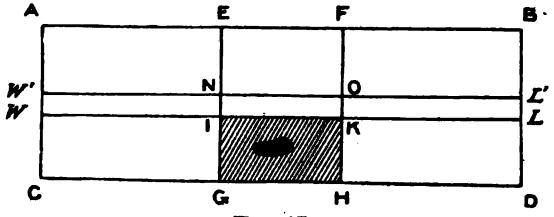

FIG. 17.

(A) $$d^1 = \frac{WL \times d \times b}{(W^1L^1 - NO)\,b}.$$

(B) $$\text{Sinkage} = d^1 - d = \frac{WL \times d \times b - (W^1L^1 - NO)\,d \times b}{(W^1L^1 - NO)\,b}.$$

But as $W^1L^1 = WL$, (B) $= \dfrac{NO \times d \times b}{(W^1L^1 - NO)\,b}$.

If the bilged compartment contains stores or other solids, the amount of water entering would be less than if the compartment were quite empty and the sinkage correspondingly less.

The general expression for sinkage from formula **(B)** is:

$$\text{Sinkage} = \frac{\text{volume of lost buoyancy in cubic feet}}{\text{area of intact water-plane in sq. ft.}}$$

The above assumes the bilged compartment in the middle of the length. Where a compartment is forward or aft, trim would occur which will be treated of later.

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Velocity of inflow of water into vessel on bilging.

A = area of hole in square feet.

d = distance of C. G. of hole below surface, in feet.

V = initial rate of flow of water in feet per second.

$V^2 = 2gd$ where g = gravity = 32.

$\therefore V = \sqrt{2 \times 32d} = 8\sqrt{d}$.

$\therefore$ Volume of water per second $= A \times 8\sqrt{d}$.

Area of wetted surface.—This is an ordinary ship calculation and is done in detail in the regular ship calculation. An approximate method is by Kirk's Analysis, which is not treated here, as it has been treated in Barton's Naval Engines, page 294.

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Naval Architecture, Thearle.
Theoretical Naval Architecture, Thearle.
Theoretical Naval Architecture, Atwood.
Theorie du Navire, Pollard & Dudebout.

PROBLEMS.

Simpson's 1st Rule.

(1) A curvilinear area has ordinates at a common distance apart, of 3 ft., the lengths being 2.45, 3.65, 5.35, 7.45, 9.50, 11.40, and 12.85 feet, respectively. Find the area of the figure in square feet.

(2) Find the area in square feet of a water-plane whose half ordinates are 0.2, 5.9, 10.5, 13.1, 14.2, 14.5, 14.5, 14.0, 12.6, 9.8, and 0.2 feet, respectively. The common interval is 15 feet.

(3) What is the area of a bulkhead whose half ordinates are 0.3, 6.0, 8.5, 10.0, 11.0, 11.8, 12.3, 12.7, and 12.9 feet, respectively, and common interval 2 feet.

Simpson's 2d Rule.

(1) Find the area in square feet of a curvilinear area having ordinates at a common distance apart, of 2.5 ft., the lengths of the ordinates being 3.50, 4.70, 5.60, 6.30, 7.00, 7.50, and 7.90 feet. Use Simpson's 2d Rule.

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(2) A curve has the following ordinates 1 ft. 4 in. apart: 10.86, 13.53, 14.58, and 15.05, respectively Find its area.

(3) The semi-ordinates of a vessel's midship section are 26.6, 26.8, 26.8, 26.4, 25.4, 23.4, and 18.5 feet, respectively, the ordinates being 3 feet apart. Below the lowest ordinate there is an area for one side of the section of 24.6 square feet. Find the area of the midship section, using Simpson's 2d Rule.

Fractional Intervals.

(1) Find the area of the plane figure which has ordinates as follows: 0.2, 2.1, 4.5, 7.0, 9.1, 12.3, 14.0, 14.5, and 14.3 feet, respectively. The intervals between ordinates are 15, 15, 15, 15, 30, 30, 30, and 30 feet, respectively.

(2) A portion of a ship's waterline has half ordinates of 0.1, 1.3, 2.4, 5.6, 11.0, 13.7, and 13.4 feet, and the spacing of the ordinates is 10, 10, 10, 30, 30, and 30 feet, respectively. Find the area in square feet, using Simpson's 2d Rule and fractional multipliers where required.

(3) Find the area of a curvilinear figure having ordinates of 0.4, 6.0, 11.8, 21.0, 26.2, 28.4, 29.0, 29.0, 28.0, 26.8, 25.4 feet, with intervals of 12, 12, 24, 24, 24, 24, 24, 24, 12, and 12 feet, respectively, between the ordinates.

5-8 Rule.

(1) A curvilinear area has ordinates 4 ft. apart, of length 10.2, 10.5, and 13.8 ft., respectively. Find the area between the first and second ordinates.

(2) Find the area between the second and third ordinates in the problem above.

(3) A watertight bulkhead has half ordinates of 7.4, 8.7, and 9.4 ft. at distance of 8, 12, and 16 ft., respectively, from the keel. Find the total area in square feet between the 12 and 16 ft. lines.

Trapezoidal Rule.

(1) Find the area of a plane curvilinear figure whose semi-ordinates are 0.2, 2.9, 5.3, 7.5, 9.2, 10.7, 11.8, and 12.6 ft., respectively, with a common interval of 2 ft.

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(2) The load water-plane of a ship has semi-ordinates of 0, 5.0, 9.6, 12.6, 14.4, 14.5, 14.4, 13.5, 11.3, 6.5, and 0.5 ft., respectively, with a common interval of 14.5 ft. Find the area in square feet, using the trapezoidal rule.

(3) Find the area of a bulkhead whose half ordinates are 0.0, 2.75, 5.50, 8.20, 10.60, and 13.20 ft., respectively, and distance between consecutive ordinates 2.5 ft.

Volume.

(1) A coal bunker has sections 15 feet apart, and the areas of these sections are 93, 118, 132, 130, and 117 square feet, respectively. Find the volume of the coal bunker in cubic feet, and the capacity in tons, allowing 43 cubic feet per ton.

(2) The curve of sectional areas of a ship's under body has ordinates of 1.5, 23.9, 50.0, 74.4, 89.6, 84.0, 59.9, 27.4, and 5.1 square feet, respectively, spaced 12 feet apart Find the volume in cubic feet.

(3) What is the capacity in cubic feet of a tank which has sectional areas of 19.4, 18.5, 17.2, 15.6, 13.6, 10.9, and 6.5 square feet, respectively, the distance between sections being 2.5 feet.

Tons per inch.

(1) The area of a waterplane is 9648 square feet. Find the tons per inch of immersion. Supposing 50 tons placed on board, how much would the vessel sink.

(2) Find the tons per inch at a waterplane which has half ordinates of 0.3, 2.3, 4.5, 6.4, 7.7, 8.6, 9.0, 9.2, 9.3, 9.1, 8.8, 8.4, 7.6, 6.2, and 3.5 feet, respectively, the ordinates being 6.5 feet apart.

(3) The tons per inch immersion of a vessel when floating in salt water at a certain water-plane is 41.8. What is the area of this plane?

Longitudinal C. G. of water-plane.

(1) The semi-ordinates of the load water-plane of a vessel 320 feet long are, commencing from forward, 0, 8.8, 15.8, 19.6, 21.3,

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22.8, 22.7, 21.0, 19.0, 14.7, and 0.2 feet, respectively. Find the distance of the center of gravity from the middle ordinate.

(2) The load waterline of a ship has semi-ordinates of 0.1, 10.3, 20.1, 27.5, 32.2, 34.0, 33.9, 31.8, 27.7, 20.7, and 9.5, respectively, at intervals of 40 feet. Find the area and the distance of the C. G. from the middle ordinate.

(3) The semi-ordinates of a water-plane, commencing from the after end, are 4.1, 9.1, 13.3, 16.8, 19.5, 21.6, 23.2, 24.4, 25.1, 25.4, 25.5, 25.2, 24.3, 22.8, 20.7, 17.7, 14.3, 10.4, 6.1, 2.2, and 1.1 feet. The distance apart is 18 feet. Find the position of the center of gravity in relation to the middle ordinate.

C. G. between consecutive end ordinates.

(1) A curve has ordinates 12, 11, and 9 feet long, 5 feet apart. Find the position of the center of gravity of the portion between the first two ordinates with respect to the end ordinate.

(2) A bulkhead has half ordinates of 0.6, 5.6, and 8.3 feet, 4 feet apart, the first being at the keel. Find the distance above the keel of the center of gravity of the portion below the 4-foot line.

(3) A curve has ordinates of 14, 12, and 9 feet, 3 feet apart. Find the distance of the center of gravity of the area between the first and second ordinates, from the first ordinate.

(1) The ordinates of an inclined water-plane of a vessel are 6 feet apart, and the lengths are 0.3, 2.3, 4.5, 6.4, 7.7, 8.6, 9.0, 9.2, 9.3, 9.1, 8.8, 8.4, 7.6, 6.2, and 3.5 feet, respectively. Calculate the distance of the center of gravity from the centerline.

(2) Find the area and transverse position of the center of gravity of "half" a water-plane, the ordinates in feet being 0.5, 6, 12, 16, 12, 10, and 0.5, respectively, the common interval being 15 feet.

(3) An area bounded by a curve and a straight line is divided by ordinates 4 feet apart, of the following lengths: 0, 12.5, 14.3, 15.1, 15.5, 15.4, 14.8, 14.0, and 0 feet, respectively. Find the position of the center of gravity relative to the base.

(1) The ordinates given below are for one-half of the main

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cargo hold of a vessel. Find the cubic capacity of the hold, and the distance of the center of gravity of one-half from the center-line. The frame spacing is 3 feet, and the distance between level lines is 4 feet 6 inches.

ORDINATES IN FEET AT FRAMES—NUMBERS.

Level lines	15	20	25	30	
No. 1	4.8	9.0	12.7	14.2	14.4
No. 2	9.8	15.0	18.7	19.9	20.1
No. 3	12.7	17.6	20.5	21.5	21.6
No. 4	14.5	19.0	21.2	21.7	21.8
No. 5	15.7	19.6	21.3	21.7	21.8

(2) From the particulars given below, find the longitudinal and transverse positions of the center of gravity of the body which is a solid bounded by a plane and curved surface.

ORDINATES IN FEET AT SECTIONS—NUMBERS.

	1	2	3	4	5
No. 1 W. L.	0.2	7.4	11.0	9.3	2.0
No. 2 W. L.	0.2	5.3	10.5	6.5	0.3
No. 3 W. L.	0.2	2.0	7.6	2.6	0.3

(3) The curve of sectional areas of a side bunker has ordinates of 142, 170, 181, 176, and 165 square feet, respectively, and the distance between ordinates is 10 feet. Find the longitudinal and transverse positions of the center of gravity of the bunker, also the capacity in tons, one ton of coal being equal to 43 cubic feet.

(1) The tons per inch of a ship's displacement at waterlines 4 feet apart, commencing at the L. W. L., are 45.3, 43.7, 41.5, 38.5, 34.3, and 0, respectively. Find the position of the C. B. below the L. W. L.

(2) A vessel is 180 feet long, and the transverse sections from the load waterline to the keel are semi-circles. Find the longitudinal position of the center of buoyancy, the ordinates of the load water-plane being 1, 5, 13, 15, 14, 12, and 10 feet, respectively.

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(3) From the particulars given below, find the fore and aft and vertical positions of the center of buoyancy of the vessel. The vessel is 120 feet long and the draft is 9 feet.

HALF ORDINATES IN FEET.

Waterlines.	Stem.	Section 2.	Section 3.	Section 4.	Sternpost.
L.W.L.	0.2	7.4	11.0	9.3	2.0
2W.L.	0.2	5.3	10.5	6.5	0.3
1W.L.	0.2	2.0	7.6	2.6	0.3
Keel	0.2	0.2	0.2	0.2	0.3

(1) A vessel is 500 feet long, 60 feet broad, and floats at a mean draft of 25 feet when in salt water. Make an approximation to her draft when she passes into river water. (Coefficient of displacement 0.5; coefficient of L. W. P. 0.6).

(2) A vessel floats at a certain draft in river water, and when floating in sea water without any change in lading, it is found that an addition of 175 tons is required to bring the vessel to the same draft as in river water. What is the displacement after the addition of the weight named?

(3) A ship floats at a draft of 28 feet in river water. The weight of the ship is 16,000 tons and the area of the load water-line is 23,500 square feet. What is the draft of the same ship in sea water?

(1) A vessel in the form of a box, 100 feet long, 10 feet broad and 20 feet deep, floats at a draft of 5 feet. Find the draft if a central compartment 10 feet long is bilged below water.

(2) A box-shaped vessel 150 feet long by 20 feet broad and 15 feet deep floats at a draft of 10 feet. Find the length of a central compartment which, when bilged, will not sink her more than 2 feet.

(3) A box-shaped vessel 120 feet long, 20 feet broad, and 16 feet deep, floats at a draft of 12 feet when a midship compartment 20 feet long is open to the sea. Find the draft when this compartment is closed and empty.

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CHAPTER IV.

CONDITIONS OF EQUILIBRIUM.

Conditions that must obtain in case of ship floating at rest in water.

(1) As seen before, the displacement must equal the weight of ship with everything on board.

(2) The downward force of the weight, from definition of C. G., must be considered as acting through C. G.

(3) The upward force of buoyancy, from definition of C. B., must act upward through C. B.

C. B. and C. G. must be in same vertical line, otherwise there will exist a couple tending toward rotation until this condition is realized.

Statical stability.—The *statical stability* of a ship is the tendency she has to assume the upright position when inclined away from that position, and is due to the conditions outlined above.

Stable equilibrium exists when, if the ship is inclined from her position of rest, she tends to return to it.

Unstable equilibrium exists when, if the ship is inclined from her position of rest, she tends to go farther away from it.

Neutral equilibrium exists when, if the ship is inclined from her position of rest, she neither tends to return to the position of rest, nor to move farther away from it.

Transverse metacenter we have had defined above. To find this point we proceed as follows:

(*A*) in Fig. 18, following, represents a cross-section of a ship. (*B*) in Fig. 18 represents the load water-plane in plan.

Now consider the ship inclined through a small angle, bringing the waterline, Fig. (*A*) to the position W^1L^1. W^1L^1 will intersect WL at the point O or at center.

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NOTE.—This is not absolutely accurate except for small angles. The proof as to the location of the point of intersection is of some length, and the student has not time to go into it.

In general.—*If a floating body is slightly inclined and maintains the same volume of displacement, the new water-plane will intersect the old water-plane in a line through the C. G. of the original water-plane.*

Now the center of buoyancy, B, will, due to change of form of immersed volume, move to a point, as B^1

Let r = half breadth.

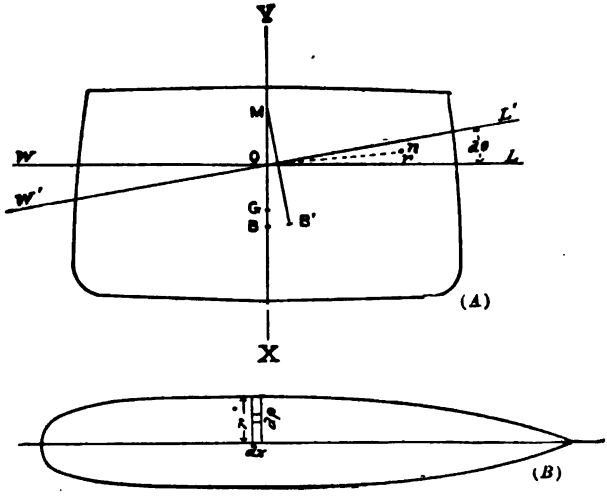

FIG. 18.

As the inclination is small, say $d\theta$

Area of triangle $OLL^1 = \frac{1}{2}r \times rd\theta$

Moment of area OL^1L = area × distance C. G. from O

$$= \frac{r}{2} \times rd\theta \times on$$

$$\text{but } on = \tfrac{2}{3}\, r \cos \frac{d\theta}{2},$$

$$\therefore \text{moment of area} = \tfrac{2}{3}\, r \cos \frac{d\theta}{2}\left(\frac{r^2}{2}\, d\theta\right)$$

$$= \frac{r^3}{3} \cos \frac{d\theta}{2}\, d\theta.$$

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Now, in the case of ships, the cross-section is symmetrical about vertical axis through O.

$\therefore$ Moment of area WOW^1 = moment area LOL^1

(1) for whole ship total change of moment =

$$\int 2 \times \frac{r^3}{3} \cos \frac{d\theta}{2} \, d\theta \, dx.$$

(dx being the increment in direction of length)

But (1) $= V \times BB^1$

But $BB^1 = BM \sin d\theta$

$$\therefore \int 2 \frac{r^3}{3} \cos \frac{d\theta}{2} \, d\theta dx = V \times BM \sin d\theta$$

as $d\theta$ is small, $\sin d\theta = d\theta$ and $\cos \frac{d\theta}{2} = 1$.

$$\therefore V \times BM d\theta = \int \frac{2r^3}{3} d\theta \, dx,$$

$$\text{or } V \times BM = \int \frac{2r^3}{3} dx,$$

$$\text{or } BM = \frac{\int \frac{2r^3}{3} dx.}{V}.$$

Now $\int \frac{2}{3} r^3 dx$ is the expression for moment of inertia of the water-planes. See Figure 18 above we find

Increment area $= d\rho \times dx$

Moment increment $= \rho d\rho dx$

Inertia increment $= \rho^2 \times d\rho dx$

Inertia $\frac{1}{2}$ W. P. $= \int_o^L \int_o^r \rho^2 d\rho dx$

Total inertia $= \int_o^L \frac{2}{3} r^3 dx$

$\therefore$ the expression generally given is B. M. $= \frac{I}{V}$ where B. M. is the vertical distance from center of buoyancy to metacenter.

I is moment inertia of water-plane about its center line.

V is volume of displacement.

EXAMPLE.—The semi-ordinates 16.6 feet apart of a water-plane are 0.2, 2.3, 6.4, 9.9, 12.3, 13.5, 13.8, 13.7, 12.8, 10.6, 6.4, 1.9, 0.2.

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If displacement up to this waterline is 220 tons, find value of B. M.

Number of Ordinate.	Semi-ordinate of Water-plane.	Cubes of Semi-ordinates.	Multipliers.	Functions of Cubes.
1	0.2	..	1	..
2	2.3	12.1	4	48.4
3	6.4	262.1	2	524.2
4	9.9	970.3	4	3881.2
5	12.3	1860.8	2	3720.6
6	13.5	2460.3	4	9841.2
7	13.8	2628.0	2	5256.0
8	13.7	2571.3	4	10285.2
9	12.8	2097.1	2	4194.2
10	10.6	1191.0	4	4764.0
11	6.4	262.1	2	524.2
12	1.9	6.8	4	27.2
13	0.2	..	1	..
				43066.4

Moment inertia $= 43066.4 \times \frac{2}{3} \times \frac{16.6}{3}$

B. M.$=43066.4 \times \frac{2}{3} \times \frac{16.6}{3} \div 220 \times 35 = 20.6$ feet.

We are therefore able, by dividing the moment of inertia of the several water-planes by the volume up to those water-planes to obtain the value of B. M., and by setting it up from our curve of C. B. to get a curve of *M*.

We may similarly demonstrate that the value of *longitudinal* B. M. is *I* about a transverse line at middle of length divided by volume.

The *I* in this direction is given by a formula of the form $\int rx^2 dx$ as seen by inspecting Fig. 18 above.

The practical application of this rule is illustrated by the following example:

It is usual to find Moment of Inertia about ordinary midship ordinate. If we call this *I* and if *y* be the distance of centre of flotation, which is C. G. of water-plane, from midship ordinate, then $I = I_0 + Ay^2$ *or* $I_0 = I - Ay^2$.

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If Disp't be 91.6 tons, interval 7.1 feet.

Number of Ordinate.	Semi-ord. of L. W. P.	Multipliers.	Products for Areas.	Multipliers for Moments.	Products for Moments.	Multipliers for I,	Products for I.
1	0.00	$\frac{1}{2}$	0.00	5	0.00	5	00.00
$1\frac{1}{2}$	1.37	2	2.74	$4\frac{1}{2}$	12.33	$4\frac{1}{2}$	55.49
2	2.67	$1\frac{1}{2}$	4.01	4	16.04	4	64.16
3	4.87	4	19.48	3	58.44	3	175.32
4	6.31	2	12.62	2	25.24	2	50.48
5	6.85	4	27.40	1	27.40	1	27.40
6	7.21	2	14.42	0	139.45		
7	7.15	4	28.60	1	28.60	1	28.60
8	6.87	2	13.74	2	27.48	2	54.96
9	6.33	4	25.32	3	75.96	3	227.88
10	5.08	$1\frac{1}{2}$	7.62	4	30.48	4	121.92
$10\frac{1}{2}$	3.56	2	7.12	$4\frac{1}{2}$	32.04	$4\frac{1}{2}$	144.18
11	0.71	$\frac{1}{2}$	.35	5	1.75	5	8.75
			163.42		196.31		959.14
					139.45		
					56.86		

Area $= 163.42 \times \frac{1}{3} \times 7.1 \times 2 = 773.5$ square feet.

C. G. from ordinate No. 6 is $\frac{56.86 \times 7.1}{163.42} = 2.47$ feet.

$I = 959.14 \times \frac{1}{3} \times 7.1 \times (7.1)^2 \times 2 = 228{,}858.$

The multipliers above being $\frac{1}{3}$ common interval to complete Simpson's rule.

By square of common interval to complete integration for inertia.

By two for both sides.

∴ Moment inertia of water-plane is

$$I_0 = 228{,}858 - (773.5 \times 2.47^2)$$
$$= 224{,}139$$

Now as $BM = \frac{I}{V}$,

$$BM = \frac{224{,}139}{91.6 \times 35} = 69.9 \text{ feet.}$$

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We now come to the consideration of the question of transverse inclinations. We have had metacenter or M, defined; we have seen how its location may be determined.

Fig. 19, below, represents a section of a ship steadily inclined at a small angle from its normal or upright position by some external force.

As the weight of the vessel has not changed, the volume of displacement must be unchanged. We must assume that no weights on board shift, therefore the C. G. remains in the same position as before.

The shape of the volume of displacement has changed, however, and the C. B. must therefore have moved.

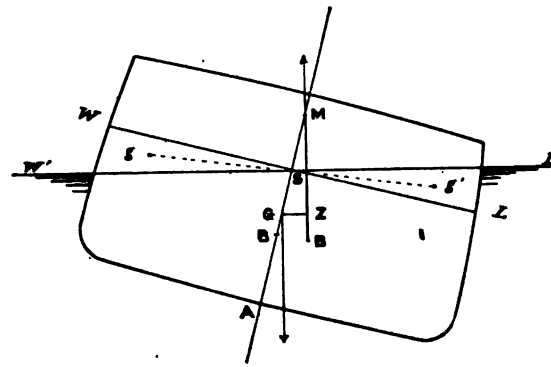

FIG. 19.

In the figure above, the section W. A. L. is considered to have been the immersed section when upright, with W. L. as the waterline in this position, and W^1AL^1 the section when inclined, with W^1L^1 the new waterline.

Therefore, the wedge-shaped volume W^1SW which has come out and is called the *emerged* wedge, must equal the similar volume L^1SL which has gone under the water and is called the *immersed* wedge.

For small angles, the Point S is on the center line of the waterplane; for larger angles this is not true and the consideration becomes more involved, and will not be treated of in this work.

Considering the ship inclined at a small angle:

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The new volume of displacement W^1AL^1 has its C. B. at B^1. The location of this point might be calculated from the drawings, as was the location of B in the upright position, but, as will be seen below, may be more easily obtained.

B^1 being new center of buoyancy, the upward force acts through it, while the weight of ship acts down through the C. G. or G.

Draw perpendicular to W^1L^1 (the plane of the surface of the water) through G and extend down, to represent downward action of weight.

Draw perpendicular to W^1L^1 (the plane of the surface of the water) through B^1 and extend up, to represent upward action of buoyancy.

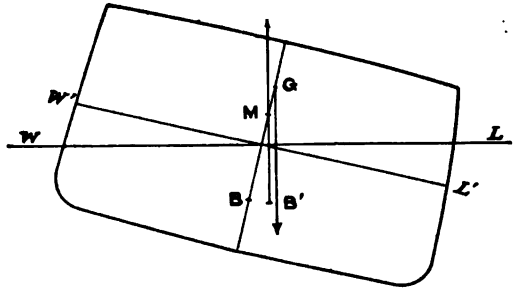

FIG. 20.

This from definition of metacenter will cut line BGS in point M, and we see that we have a couple.

Draw GZ from G perpendicular to vertical line through B^1.

GZ = arm of couple.

Moment of couple = $W \times GZ$.

Where W = weight of ship = also force of buoyancy.

Inspection of figure will indicate that this couple is tending to return the ship to the upright position.

Now if the relative position of Z and M was as in Fig. 20 above it is evident that the couple acting would tend to carry the ship farther away from the upright; and if G and M were coincident there would be no couple.

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We therefore see that for a ship to float freely and be in stable equilibrium, the following conditions must exist:

(1) Weight of water displaced must equal total weight of ship.

(2) C. G. of ship must be in the same vertical plane as C. G. of displaced water, *i. e.*, center of buoyancy.

(3) C. G. must be below the metacenter.

It will be noted in the definition of metacenter in Chapter II the angle is defined as small. In ordinary ships, in practice, the point M does not change for inclinations up to 10° or 12°, but beyond this it moves.

The following general propositions as to *initial stability* may be stated:

If G is below M, the ship is in stable equilibrium.

If G is coincident with M, the ship is in neutral equilibrium.

If G is above M, the ship is in unstable equilibrium.

The term GM is called *metacentric height;* more properly the transverse metacentric height.

Assuming, as is the case up to 10° to 12°, that M remains fixed, $GZ = GM \sin \theta$,

$\therefore$ moment of couple is $W \times GM \sin \theta$.

If G is below M, this moment is tending to right the ship;

$\therefore W \times GM \sin \theta$ may be called the *moment of statical stability* at the angle θ, and this method is called the *metacentric* method of determining a vessel's stability.

The two things to be found are G and M.

We have seen how to find M.

The location of G depends solely on vertical distribution of weights on the ship, and its determination will be treated of later; it is a matter of long and laborious calculation when considered as a design problem. For ships actually existing it is easy of determination, as will be seen later.

Metacentric diagram.—We have seen how to calculate and plot CB and M. If to this combination we add the plotting of the value of G, we obtain the metacentric diagram. For a merchant ship, the position of G varies materially, due to different conditions of loading, and the range of drafts is also considerable. In warships these variations are not so wide, being due chiefly to con-

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sumption of stores, coal, and ammunition. The metacentric diagram is as shown in Fig. 21 following.

Inclining experiment.—The object of this experiment is to determine the vertical location of the C. G. It is generally performed when the vessel is approaching completion and weights may be determined accurately to check the results of design calculations.

In practice, the following points should be considered:

(1) Ship should have no free water in it, *i. e.*, all boilers, inner bottoms, tanks, &c., must be empty or entirely full.

(2) Ship should be moored head to wind and tide, and preferably where neither exist.

(3) No loose weights liable to shift should be allowed on board.

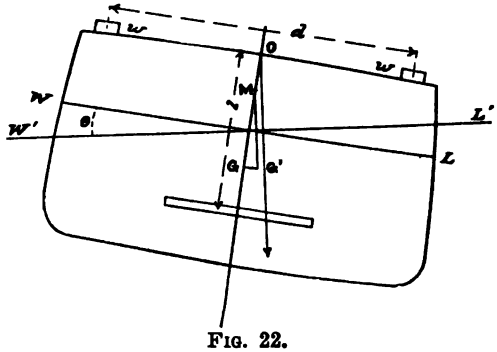

FIG. 22.

(4) Such crew as is on board at time of experiment should stay in center line and keep still.

Weights of known amount are shifted transversely across the deck and the distance of their C. G. from longitudinal center line of ship is carefully noted. The weight of ship itself can be determined from draft and displacement curves.

Considering Fig. 22,

let W = whole weight of ship,
w = inclining weight,
G = center of gravity of original ship.

If the weight, w, be moved a distance, d, the C. G. of the whole weight, W, will move a distance, GG^1,

$$(1) \text{ or } GG^1 = \frac{w \times d}{W}.$$

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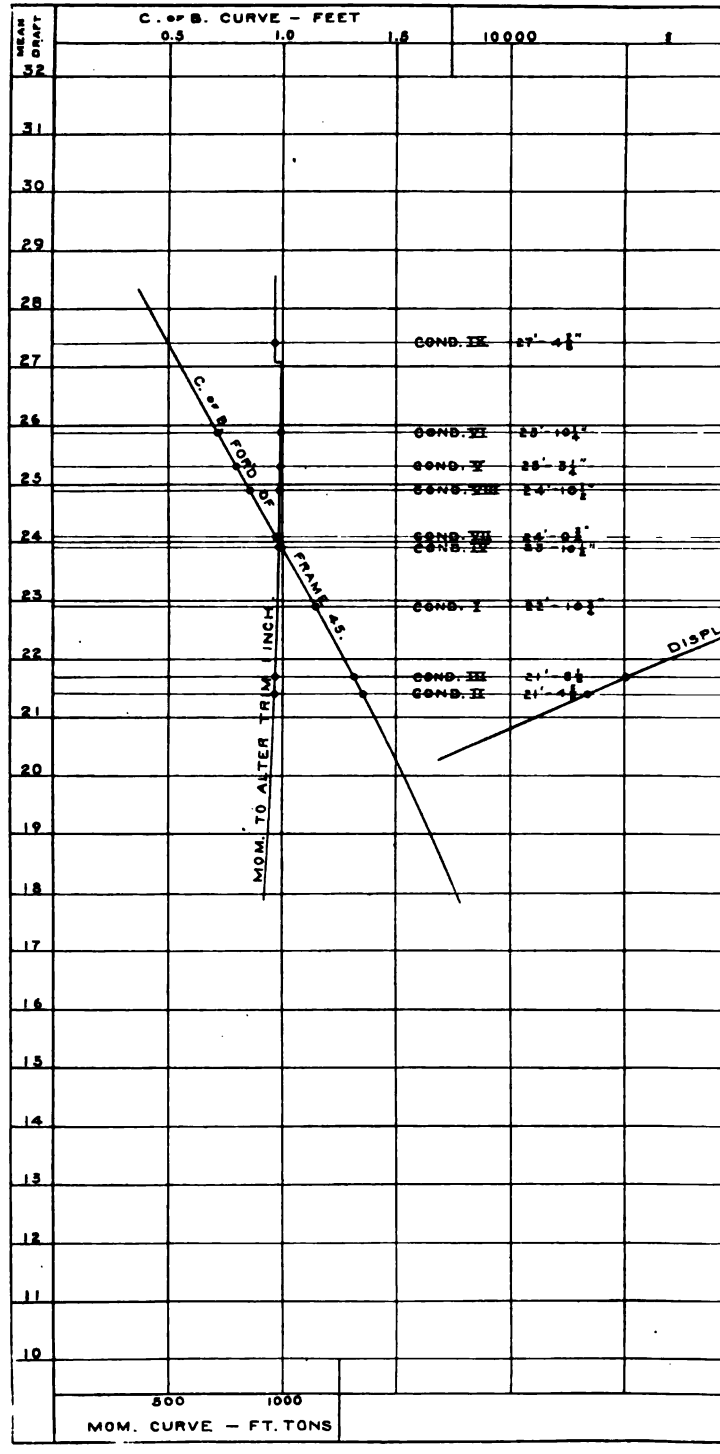

FIG. 21.—DISPLACEMENT AND OTHER C

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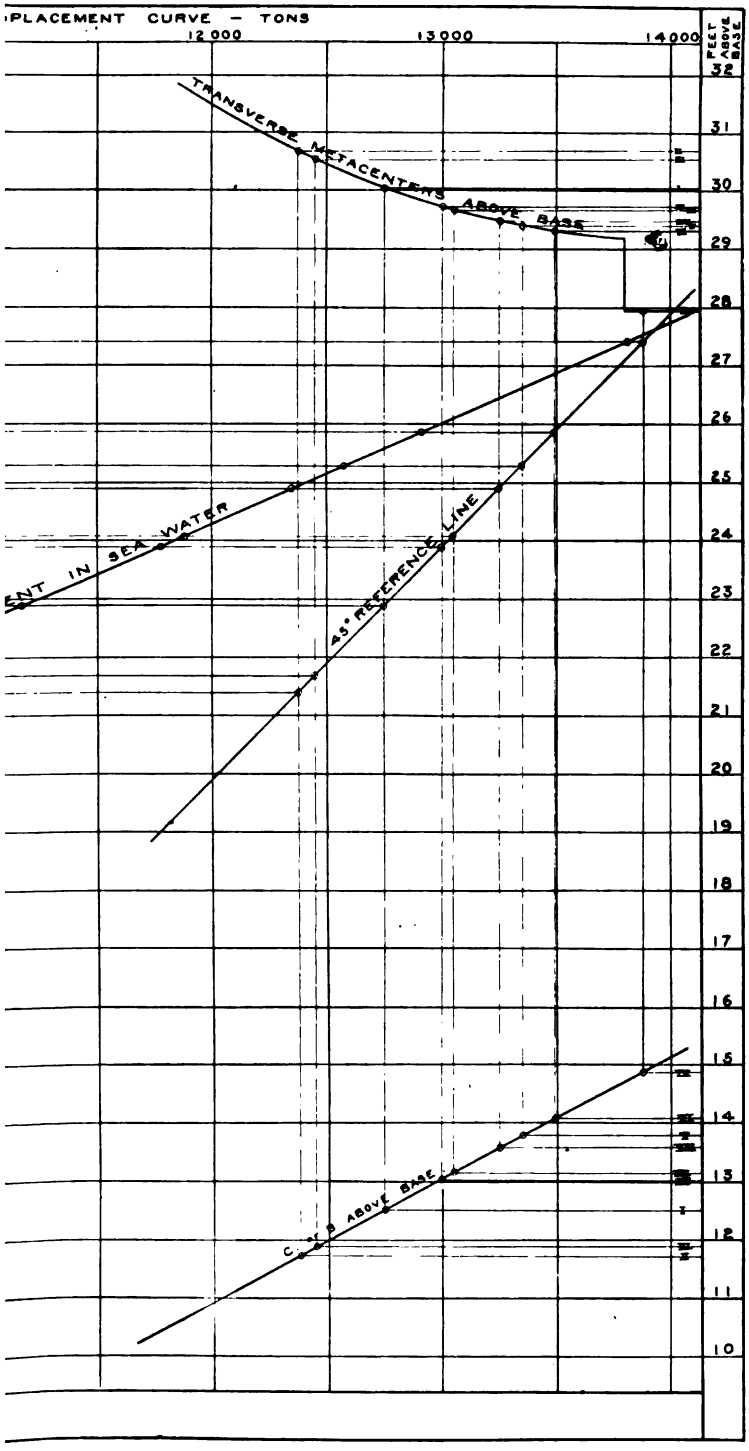

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This the student has seen in his studies in mechanics.

Now, unless there are some external forces to prevent, the ship will incline, due to the movement of these weights, to an angle of, say $\theta°$.

$$\text{From inspection, } \tan\theta = \frac{GG^1}{GM},$$

$$GM = GG^1 \cot\theta;$$

$$\text{or, from (1), } \quad GM = \frac{w \times d}{W} \cot\theta.$$

The only term in this equation unknown is tan θ. In practice, it is usual to suspend a plumb bob from some point O down a hatch or turret opening and at some convenient point on a lower deck to erect a batten parallel to the W. L. in upright position. If this plumb bob from point of suspension to batten in upright position has a length, l, and if, after inclination, the plumb bob has swung over on the batten a distance, a,

$$\tan\theta = \frac{a}{l} \text{ or } \cot\theta = \frac{l}{a},$$

$$\text{we can write } GM = \frac{W \times d \times l}{a W}.$$

Ordinary values for G. M. are:

Battleship	$3\frac{1}{2}$ ft.	to	$5\frac{1}{2}$ ft.
Monitor	9 "	"	14 "
Armored high-sided cruiser	3 "	"	5 "
Protected cruiser	$1\frac{1}{2}$ "	"	3 "
Gunboat	2 "	"	$2\frac{1}{2}$ "
Torpedo-boat destroyer	$1\frac{1}{2}$ "	"	$2\frac{1}{2}$ "
Sailing vessels, frigates	4 "	"	5 "

The value of G. M., as we have seen, may be found by calculating the location of M from the lines of the ship, and we may obtain the vertical location of G by calculation or by the inclining experiment.

For the vessel to be "stiff," that is, difficult to heel by external forces, the value of G. M. must be large. For steadiness in a seaway, the metacentric height must be small.

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The value to be given G. M. is a point for the designer to settle, and depends on the type of ship and the qualities desired.

With a soft-ended ship where the ends are liable to be riddled in action and the waterplane destroyed, G. M. should be considerable, as also in sailing ships, to permit them to stand up under canvas.

For purposes of the gun platform it is desirable that G. M. be not too large, as a ship with a large G. M., when inclined, returns to the upright with a jerk.

As will be seen later in the discussion on stability, for a high-sided vessel it is possible for G. M. to be very small and still have a perfectly safe and stable ship, provided the waterplane is left intact. This is not an unusual condition in merchant ships, some of which even have a small initial negative G. M.

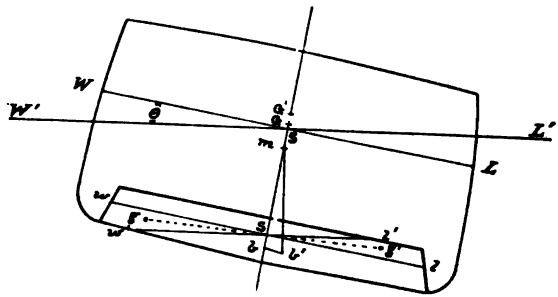

FIG. 23.

Effect on initial stability of free water in ship.—It will be noted in the inclining experiment that special attention was given to the necessity for having no free water.

Free water is water having a free surface.

It will be readily seen, on consideration, that if any boiler or compartment is completely filled with water, it will simply be a dead weight; but consider this sketch (Fig. 23).

If the ship be heeled to an angle, θ, the water in the tank will run over until its free surface is parallel to the new waterline.

As above,

$$\text{Wedge } wsw^1 = lsl^1 = v.$$

If their respective CG's be g and g^1, and b be the original CG of

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water, we will find the CG of the whole amount of water moved to some pont b^1 and if V_1 be whole volume of water in the tank $V_1 bb^1 = v \times gg^1$,

$$bb^1 = \frac{v}{V_1} \times gg^1,$$

and bb^1 is parallel to gg^1 from the principles of moments.

Now above we found that the moment of transference of the wedges WSW^1 and LSL^1 was equal to the volume of wedge $\times$ distance of transference of CG of wedge and was $I \times \theta$.

Because (see Fig. 19) $BB^1 \times V$ of whole ship $= gg^1 \times v$ wedge.

$BB^1 = BM \sin \theta$ or $= BM \times \theta$, as θ is a small angle,

$$BM = \frac{I}{V}$$

$$\therefore \frac{I}{V} \times V \times \theta = I \times \theta = gg^1 \times v \text{ of wedge.}$$

Similarly for the wedge wsw^1 and lsl^1 it is, as may be shown,

$$v \times gg^1 = i \times \theta.$$

i = moment of inertia of free surface of water about a fore-and-aft axis through S; θ = angle of inclination.

$$V_1 \times bb^1 = i \times \theta,$$

$$\therefore \quad bb^1 = \frac{i \times \theta}{V_1};$$

$$\text{or } bb^1 = bm \times \theta,$$

$$bm \times \theta = \frac{i \times \theta}{V_1}$$

$$bm = i/V_1.$$

Now the CG of the free water having moved to b^1, the weight acts in the line $b^1 m$ down through b^1, perpendicular to new water-line, and the effect on the ship is that of a weight whose CG is at m, which is called the virtual CG of the water.

We may illustrate by supposing a pendulum suspended at m, with its bob at b. If now the ship is inclined, the bob moves to b^1, the pendulum assuming the position mb^1. This is, in principle, identical with the case of the water.

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The CG of the ship cannot now be assumed at G but has risen to a point G^1, and if W_1 = the weight of water in tons $= \frac{V_1}{35}$.

Then if W = whole weight of ship,

$$W \times GG^1 = W_1 \times bm,$$

$$= \frac{V_1}{35} \times bm,$$

$$GG^1 = \frac{V_1 \times bm}{35\,W} = \frac{V_1}{V} \times bm,$$

V being volume of whole displacement, W,

but $bm = \frac{i}{V_1}$,

$$GG^1 = \frac{V_1}{V} \times \frac{i}{V_1} = \frac{i}{V}.$$

The new moment of stability at angle θ is

$$W \times G^1M \times \sin\theta = W \times (GM - GG^1) \sin\theta$$

$$= W\left(GM - \frac{i}{V}\right) \sin\theta.$$

The metacentric height being reduced by $\frac{i}{V}$.

It is to be noted that the amount of water does not affect the result, but only the *moment of inertia of the free surface.* A small quantity of water having a large free surface will have a greater effect than a large quantity with a smaller free surface.

It is thus apparent why water having a free surface affects the determination of the location of CG by the inclining experiment, and also, in a general way, its effect on the initial stability.

We have shown above how to determine the location of the *longitudinal metacenter.* The general bearing that this point has on the conditions of equilibrium of a ship may be seen from considering sketch (Fig. 24):

For a given waterline, as WL, let B be center of buoyancy.

Draw BM perpendicular to this WL.

If trim be changed by small angle so that waterline is at W^1L^1, the volume of displacement remaining the same, the CB will move to B^1.

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Draw B^1M perpendicular to new waterline through B^1 and the point M where BM and B^1M intersect, is the longitudinal metacenter.

For any condition of equilibrium we know that CG and CB must be in the same vertical line. So, given the length of a ship, we have

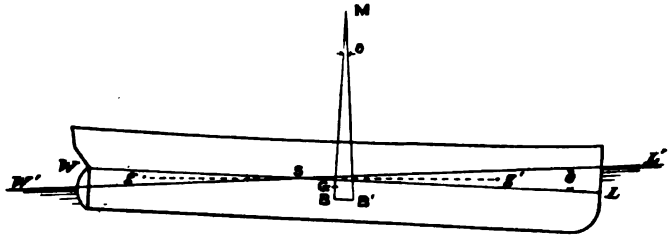

FIG. 24.

only to determine the longitudinal position of B to know the longitudinal position of G.

Change of trim due to longitudinal shifting of weights on board. —*Change of trim* = sum of *change of draft* forward and aft.

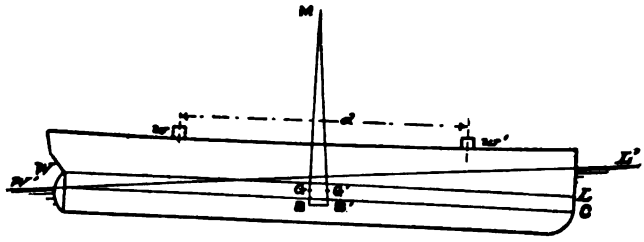

FIG. 25.

Consider Fig. 25.

Let w be weight on deck when ship floats at line, WL. If this is now moved forward a distance, d, to position w^1 the trim of the ship is changed. CG will move from G to G^1, GG^1 being parallel to line joining the original and final positions of w.

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Let W = displacement of ship,

$$GG^1 \times W = w \times d,$$

$$\therefore \quad GG^1 = \frac{w \times d}{W}.$$

CB will move from B to B^1.

Draw W^1C from W^1 parallel to WL and meeting forward perpendicular at C; then $CL = W^1W$ and change of trim is $WW^1 + LL^1 = CL^1$ say. The angle of inclination between W^1L^1 and WL is say θ and equals angle CW^1L^1.

$$\tan \theta = \frac{CL^1}{\text{length}} = \frac{x}{L}.$$

But we also have

$$\tan \theta = \frac{GG^1}{GM},$$

$$\therefore \frac{x}{L} = \frac{GG^1}{GM} = \frac{w \times d}{W \times GM} \text{ or}$$

$x = \frac{L \times w \times d}{W \times GM}$ = change of trim due to moving weight, w, through distance, d, feet.

In inches this is $\frac{12 \times w \times d \times L}{W \times GM}$.

Moment to change trim 1 inch is $w \times d = \frac{W \times GM}{12L}$;

we must know { Vertical position of G, Vertical position of M, Displacement, Length.

All of these are determined in making the design. As BG is small, a reasonable error in calculating vertical position of G makes little difference in the value of moment to change trim 1 inch. In ships of ordinary form, longitudinal BM approximates closely to length of ship, and to GM also; $\therefore$ an approximation to moment to change trim 1 inch is $\frac{W}{12}$.

This moment to change trim 1 inch is calculated to various WL's and in the U. S. Service a curve plotted.

Effect on trim of adding a weight of moderate amount.—If it be desired to place a weight on board so that the vessel will not

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change trim, it must be placed so that its *CG* will be in the same vertical line as the *CB* of the added buoyancy.

If we assume a ship floating at a certain waterline and imagine her to sink down a small amount so that the new water-plane is parallel to the original water-plane, the additional buoyancy is formed of a parallel layer of nearly the shape of the original water-plane. The buoyancy, acting upward, of this parallel layer, will act through the *CG* of the layer, which will be very nearly over the *CG* of the original water-plane; therefore, to place a weight of moderate amount on a ship so that no change of trim occurs, we must place it vertically over *CG* of original water-plane. The distance the ship will sink = weight added ÷ tons per inch at this waterline.

We have assumed—

(1) That tons per inch do not change within the limits of change of draft.

(2) *CG* of parallel layer of added buoyancy is in the same vertical line as *CG* of original water-plane.

Both these are true for moderate amounts of sinkage and ordinary ship-shaped forms.

For larger changes in draft, it is not reasonable, as *CG* of water-planes changes from water-plane to water-plane.

As a rule, water-planes are fuller aft than forward, near the *LW* plane, and therefore the *CG* of water-planes would move aft as draft increases.

If now we wish to add a weight of moderate amount in some position forward or aft, we may consider—

(1) That it is added over *CG* of water-plane and calculate sinkage due to this.

(2) That it is then moved forward, and we may obtain change of trim by dividing, weight, multiplied by its distance from *CG* of water-plane, by moment to trim ship 1 inch.

To estimate the displacement of a vessel when floating out of designed trim.—If a ship floats parallel to her designed *LWL*, we can determine her displacement readily by the curve of displacement. If a weight already on board be shifted aft, the ship will change trim by the stern. The new *WL* will pass through *CG* of

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original water-plane, an the displacement will be the same as at original waterline, no weight having been added.

Taking an actual ship in the water: If we measure draft aft and forward—

$$\frac{\text{Draft aft} + \text{draft forward}}{2} = \text{mean draft.}$$

On profile, draw the line parallel to designed WL at this mean draft line. The displacement will not be exactly correct measured to the lines. wl in Fig. 26 represents the line parallel to designed WL at mean draft, and WL represents actual waterline.

If F be CG of water-plane, wl, draw W^1L^1 through F parallel to WL; then the actual displacement will be that up to W^1L^1 (which is nearly the same as that up to WL) + displacement of layer WLL^1W^1. Displacement up to WL may be found at once from displacement scale.

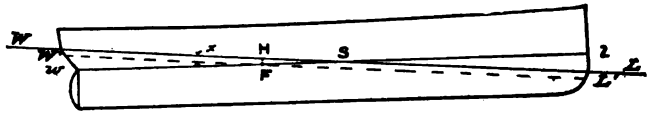

FIG. 26.

Let T = tons per inch at waterline WL, which is very nearly the same for WL and W^1L^1;

$SF = d$ inches, say = distance CG of water-plane wl is abaft middle of length.

The angle between wl and WL is such that

$$\tan\theta = \frac{wW + lL}{\text{length of ship}} = \frac{\text{amount out of trim}}{\text{length of ship}}.$$

Let x = thickness of layer WLL^1W^1 in inches.

From triangle SFH

$$\tan\theta = \frac{x}{d} \text{ very nearly.}$$

$$\therefore x = d\tan\theta = d \times \frac{\text{amount out of trim}}{\text{length of ship}}.$$

and xT = displacement of layer.

$\therefore$ whole displacement = displacement from mean draft + xT.

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Effect of Adding Weights.—Such calculations may be utilized in the case of damage to the ship which admits water into a certain number of compartments. In such case of admission of water, three cases may be considered: *1st,* The compartments may be so situated that they are limited by a water-tight flat below the exterior waterline and the damage is such that the compartment is completely filled. In such a case, the water admitted acts just as so much dead weight, and the effects of it can be calculated in the manner indicated above. *2d,* The water may be admitted into a compartment where, while not in free communication with the exterior of the ship, it has a free surface. In such case it has a more serious effect on the stability than if it were a fixed weight, for, as has been explained, with a free surface, the water would move towards the inclined side, and, in addition to the upsetting arm which would be caused by the water considered fixed, there is an additional upsetting moment introduced by what *would be* the righting arm in a similar underwater body of a ship of the same shape, as has been explained apropos of the metacentric method. This additional upsetting arm must be added to the other upsetting arm already considered in the case of the fixed weight. *3d,* The compartment considered may be in free communication with the exterior water, and at the same time have a free surface. In this case, such a compartment may be considered as a part subtracted out of the ship at the waterline. Her load plane of flotation is seriously diminished in area, and, as a consequence, the metacenter is lowered and the righting arms diminished. In such a case, every inclination of the ship produces a new admission of water, so that if it is attempted to calculate the final position of equilibrium, it must be done by successive approximations.

It is needless to say that such calculations are extremely laborious and give little satisfaction after their completion. They have been made, however, in a few cases, in which the ends of the ship are supposed to be ridled and fully thrown open to the sea. The whole middle part of the ship covered by armor is supposed to remain intact, thus reducing the vessel to a shape which can be considered as a new vessel altogether, with certain long projections

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extending from the middle part and entirely underneath the water in the upright position.

Effect on trim of ship due to adding a weight of considerable amount.—The assumption made in previous investigations will not hold. In this case, allowance must be made for the following:

(1) Variation of tons per inch as the ship sinks deeper.

(2) Center of gravity of water-plane does not remain in same transverse section.

(3) Addition of large weight will alter location of CG of ship.

(4) Difference of form of immersed volume will alter position of B and value of BM as area of water-plane, and therefore the moment of inertia will change.

(5) Items (3) and (4) will alter value of moment to trim ship 1 inch.

For most cases, in practice, the following procedure will suffice:

(a) Assume weight so added that ship sinks parallel to original position.

(b) Find from curve of tons per inch the tons per inch at original load waterline.

(c) Divide added weight by this (b) to get first approximation to sinkage.

(d) Add the first approximation (c) to the original draft.

(e) Obtain tons per inch at the draft found from (d).

(f) Find mean of tons per inch from (b) and (e).

(g) Divide added weight by result of (f) for second approximation to sinkage.

(h) Add this amount (g) to original draft.

Now, one assumption made in (e) presupposes that the weight added be added over the CG of the layer of added displacement.

To approximate to the CG:

(i) Find CG water-plane at original draft.

(j) Find CG water-plane at draft (h).

(k) In profile connect (i) and (j), and bisect line.

Now, to find the alteration in position of CG of ship:

If W = weight of ship,

w = weight added,

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x = distance between CG of added weight and CG of ship,

(1) then change of CG is $\frac{w \times x}{w + W}$.

Now, referring to (4) above:

(m) Knowing new draft, the new vertical location of CB may be obtained from curve of center of buoyancy.

(n) Knowing new draft, the new value of BM may be obtained from displacement curve; and as we know new location of G,

(o) The value of longitudinal GM may be obtained.

(p) Using this and new displacement, we can obtain new value of moment to change trim 1 inch.

Now we may consider the weight shifted from the position, assumed above to give parallel sinkage, to the actual position and measure the distance.

(q) Weight added, multiplied by longitudinal shift will give moment to change trim.

(r) (q) ÷ (p) = change of trim total.

This is to be divided up in the ratio of distance from bow to CG water-plane, and from stern to CG water-plane, to get the change forward and aft.

The above is to a certain extent an approximation but is generally sufficiently accurate.

To determine position of a weight on board a ship such that draft aft shall remain constant whether weight is on board or not.—This may be a special case, such as desiring to know how to locate a coal bunker or cargo space so that draft aft shall be the same whether coal or cargo is in the ship.

Find first:

(1) Length of ship = L say.

(2) Displacement, normal = Δ.

(3) CG water-plane (condition 2) from $AP = d$.

(4) Longitudinal BM (condition 2) = BM.

(5) Longitudinal GM (condition 2) = GM.

(6) Tons per inch (condition 2) = x.

(7) Weight of coal or cargo to be carried = w.

Moment to change trim 1 inch = $\frac{GM \times \Delta}{12 \times L} = T$.

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The parallel sinkage, supposing coal placed with its CG in same line as CG of water-plane $= \frac{w}{x} = k$.

Therefore, the coal must be shifted forward from this position a distance such that a change of trim of $2k$ is produced.

Therefore, a forward moment of $T \times 2k$ foot-tons is required, and the distance forward of CG of water-plane that the CG of coal should go is

$$\frac{T \times 2k}{w} \text{ ft.}$$

Therefore, if CG of coal is placed $\left(d + \frac{T \times 2k}{w}\right)$ ft. forward of AP, the condition desired will be obtained.

Change of trim caused by a compartment being opened to the sea.—Assume a ship bilged, filling the forward trimming tank to bulkhead AK.

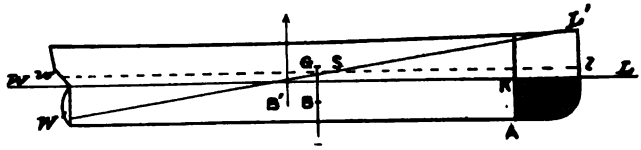

FIG. 27.

Consider Fig. 27.

This may be treated in two divisions:

(1) Determine amount of mean sinkage due to loss of buoyancy.

(2) Determine change of trim caused.

The ship, due to damage, loses an amount of buoyancy = volume of bilged compartment to original WL, and if she sinks parallel (assume), will settle until the volume of added layer is equal to volume of bilged compartment, *i. e.*, volume $wlLW$ = volume KLA.

If x be distance between wl and WL,

$x \times$ area water-plane = volume KLA.

$$\text{(a) } x = \text{in ft.} \frac{\text{volume } KLA \text{ (in cu. ft.)}}{\text{area water-plane (in sq. ft.)}}$$

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Now turning to change of trim caused:

If weight of ship $= W$,

CG is at G,

CB is at B.

Having lost the buoyancy of the compartment bilged, the CB will move to B^1,

Then weight will act down through G,

Buoyancy will act up through B^1.

(b) Forming a couple $W \times BB^1$ foot-tons, tending to trim ship forward.

(c) We must find moment to change trim 1 inch for water-line, wl.

(This is not absolutely correct. It would be more correct to take mean of moments to change trim for wl and for W^1L^1.)

Then change of trim $=$ (b) $\div$ (c) $= d$.

The new WL will intersect the waterline wl at its CG at S.

Measure distance from S to AP,

and from S to FP.

Divide d in ratio of these distances and apply to draft forward and aft and result will be obtained.

Problems.

Transverse metacenter.

(1) A box-shaped lighter is 100 feet long, 28 feet broad, and displaces 360 tons in salt water. Find the height of transverse metacenter above the bottom of the keel when the vessel floats on an even keel.

(2) A cylindrical vessel 100 feet long and 15 feet in diameter floats with its axis at the waterline. Find the height of the transverse metacenter above the center of buoyancy.

(3) The half ordinates of the load water-plane of a vessel are 6 feet apart, and their lengths are 0.3, 2.3, 4.5, 6.4, 7.7, 8.6, 9.0, 9.2, 9.3, 9.1, 8.8, 8.4, 7.6, 6.2, and 3.5 feet, respectively. The displacement to this waterline is 156 tons in salt water. Find the height of transverse metacenter above the center of buoyancy.

(1) A box-shaped vessel 120 feet long, 25 feet broad, and 15

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feet deep, floats at a draft of 10 feet. Find the distance of the longitudinal metacenter above the center of buoyancy.

(2) The moment of inertia of a water-plane of 22,500 square feet about an axis 20 feet forward of the center of flotation, is found to be 254,000,000 in foot-units. The displacement of the vessel being 14,000 tons, find the longitudinal B. M.

(3) The semi-ordinates of the load water-plane of a vessel, 30 feet apart, are, commencing from forward, 0.1, 5.3, 10.8, 15.0, 17.6, 18.5, 18.4, 17.5, 15.3, 10.8, and 3.8 feet, respectively. The displacement is 2210 tons. Calculate the distance of the longitudinal metacenter above the center of buoyancy.

(1) A ship displacing 9972 tons is inclined by moving 38 tons 52 feet across the deck, and a mean deviation of 8¾ inches is obtained by pendulums 15 feet long. What is the G. M.?

(2) What weight is required to be moved 50 feet across the deck of a ship of 8500 tons displacement to incline her 6 degrees when she has a metacentric height of 4 feet?

(3) A vessel is heeled by moving a known weight a certain distance across the deck; what is the expression for the metacentric height of the vessel in terms of the weight moved, the distance moved through, the displacement of the vessel, and the angle of heel? Prove the formula. What will be the angle of heel if a weight of 30 tons is moved 45 feet across the deck of a vessel of 5500 tons, the G. M. being 3.25 feet?

(1) A vessel 300 feet long and 2100 tons displacement has a longitudinal metacentric height of 480 feet. Find the moment to change trim 1 inch.

(2) A water-plane has an area of 13,200 square feet, and its moment of inertia about a transverse axis 14 feet forward of its center of gravity works out to 79,639,726 in foot-units. The vessel is 350 feet long, and has a displacement to the above waterline of 5625 tons. Determine the moment to change trim 1 inch, the center of gravity being 7 feet 6 inches above the center of buoyancy.

(3) Find the moment to change trim 1 inch of a vessel 420 feet long, having given the following particulars: Longitudinal meta-

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center above center of buoyancy, 452 feet; center of gravity above center of buoyancy, 10 feet; displacement, 14,300 tons.

(1) A vessel 310 feet long and 2350 tons displacement has a longitudinal metacentric height of 385 feet. Find the change of trim caused by moving a weight of 6 tons already on board through a distance of 175 feet from forward to aft.

(2) A vessel floats on an even keel at 15 feet draft. She is 280 feet long and displaces 3100 tons, and the longitudinal metacentric height is 326 feet. How far must a weight of 40 tons on deck be moved to make her draw 16 feet aft?

(3) A ship of 16,000 tons displacement and 450 feet in length has a moment to alter trim of 1650 foot-tons, and trims 4 inches by the head. How will she trim after transferring 50 tons of ammunition from the forward to the after magazine, the distance being 240 feet?

(1) A vessel is floating at a draft of 12 feet 6 inches forward, and 14 feet 3 inches aft. The tons per inch is 20; length, 300 feet; center of flotation, 12 feet abaft the middle of length; moment to change trim 1 inch, 320 foot-tons. A weight of 30 tons is placed 30 feet from the forward end of the ship. What will be the new drafts of water?

(2) A vessel 360 feet long trims 6 inches by the stern at a mean draft of 18 feet. The tons per inch at this draft is 24; center of flotation, 15 feet abaft the half length; moment to change trim 1 inch, 450 foot-tons. What weight placed 45 feet from the stem will bring her to even keel, and what will be the new draft?

(3) A ship is floating at a draft of 21 feet forward and 22 feet 6 inches aft, just before the following weights are placed on board:

Weight.	Distance from C. G. of Water-plane.
25 tons	60 feet forward.
15 "	80 " "
30 "	30 " "

What will be the new draft forward and aft, the moment to change trim being 800 foot-tons, tons per inch 35, and center of flotation at the half length?

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CHAPTER V.

STABILITY AT LARGE ANGLES OF INCLINATION.

Up to this point all the problems which we have considered have been treated by what is called the *metacentric method.* This presupposes that, for the limits within which the inclinations take place from any cause, the verticals through the different centers of buoyancy all practically meet at the same point, called the metacenter, which was defined. It was pointed out at the time that for ordinary ships this method was only applicable for transverse inclinations up to 10 or 12 degrees. It may now be mentioned that it is only applicable to longitudinal inclinations very much smaller in angular measure, but is practically sufficiently accurate, in most cases, within a range of a change of trim from 5 to 10 feet from the normal.

A general investigation of the stability at large inclinations necessitates methods more accurate and of more extended application; in other words, such as can be applied to all angles of heel. For such purposes it is necessary to calculate the actual righting arm for any inclination corresponding to any given displacement. Numerous methods have been proposed and a number are actually in use for making these calculations. Most of them are derived from what is known as Atwood's Formula.

Statical Stability at Large Angles of Inclination.

Atwood's Formula.—In the preceding chapters we have dealt only with the initial stability or stability at small angles of inclination.

In actual service this is not sufficient, as the ship is bound to be inclined beyond the 10 or 12 degrees to which this method is applicable.

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Consider Fig. 28, representing the cross-section of a ship inclined to an angle θ.

WL represents original waterline.

B represents original CB.

W^1L^1 represents waterline in inclined position.

W^1L^1 intersects WL in point S, and, as stated above, as this is a large angle, it will not be in center of ship.

Volume WSW^1 is, as before, the emerged wedge.

Volume LSL^1 is, as before, the immersed wedge.

g and g^1 are respective positions of the centers of gravity of these wedges.

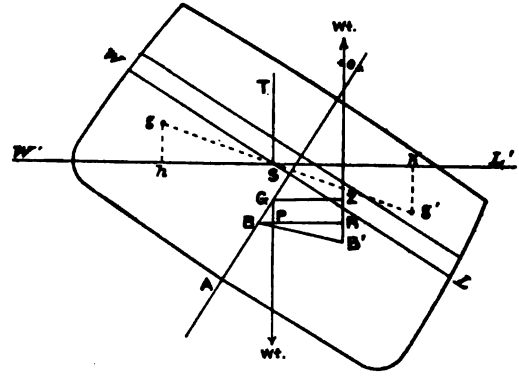

FIG. 28.

The volume of displacement has not changed; therefore, volumes of these wedges are equal.

Let v = volume of wedge.

The center of buoyancy of vessel, when inclined, is B^1. The upward support of buoyancy acts through B^1. The downward force of weight acts through G, the center of gravity of ship.

Draw GZ and BR perpendicular to the vertical through B^1. Draw gh and g^1h^1 perpendicular to new waterline W^1L^1.

(1) The moment of the couple tending to right the ship is

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$W \times GZ$, or, as we term it, the *moment of statical stability* where W = displacement of ship.

$$GZ = BR - BP,$$
$$= BR - BG \sin \theta.$$

(2) $\therefore W \times GZ = W\,(BR - BG \sin \theta)$.

By examination it will be seen that all the terms of the above are known, except BR. We may obtain this as follows:

The new volume W^1AL^1 is obtained from the original volume WAL by shifting the volume, v, through a horizontal distance hh^1.

$\therefore$ the horizontal shift of center of buoyancy is $BR = \frac{v \times hh^1}{V}$

where V = original volume of displacement = $W \times 35$.

$\therefore$ the moment of statical stability from (2) is

$$W\left(\frac{v \times hh_1}{V} - BG \sin \theta\right) \text{ foot tons.}$$

This is known as Atwood's Formula.

(3) The righting arm or lever GZ is $= \frac{v \times hh^1}{V} - BG \sin \theta$.

If, therefore, we wish to know the length of the righting arm at any angle of inclination, we must know—

(1) Location of CB in upright position.

(2) Location of CG of ship.

(3) Volume of displacement, V.

(4) Value of moment of transference of wedges parallel to the new waterline, *i. e.*, $V \times hh^1$.

The determination of (4) involves a considerable amount of calculation and will be explained later.

Supposing, however, that we are able to obtain them, we wish to plot a *curve of statical stability.*

The lengths of GZ vary as the angle of heel varies. Usually GZ increases gradually to a maximum, then decreases to zero, and then becomes negative, indicating that beyond this angle, the couple $W \times GZ$ becomes an upsetting couple instead of a righting couple.

The early method of calculating the righting arm for a given displacement is known as Barnes' Method. For every 10 degrees

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of inclination, the volumes of the wedges, v, are calculated, and also their centers of volume, g_1 and g_2. (See Fig. 29).

Certain corrections are made in the calculations, owing to the fact that the point, S, is not, in general, on the middle line. Into the details of this calculation it is not necessary to enter.

The result finally obtained is a serious of values of the arm BR from o inclination up to any inclination desired; usually carried up to 90 degrees. From each of the ordinates thus obtained is deducted the quantity $BG \sin \theta$; BG being the distance of the actual center of gravity above the center of buoyancy. This quantity, it will be observed, when plotted, gives a curve of the form of a sinus-

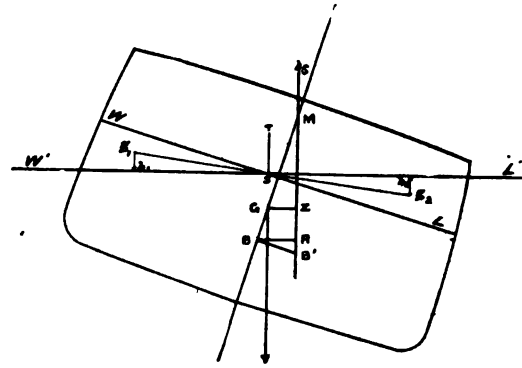

FIG. 29.

oid, and, as the center of gravity is, in almost all ships (except racing yachts with heavy lead keels) above the center of buoyancy, this term will be always subtractive. The resultant values will be the righting arms GZ.

Let us suppose that the position, G, the center of gravity for a given displacement of the ship, is determined. We can construct a curve with the actual righting arm GZ for each inclination, and we will then have a curve of the shape referred to. It will be observed (see Fig. 31) that the curve starts with a value of the righting arm, o, at the upright, which rapidly increases and finally reaches a maximum; thence decreasing until it finally crosses the axis, again becoming o. It is at the angle indicated by this max-

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imum point that the vessel has her greatest righting moment and resists with the greatest power a force tending to upset her. At the point where the curve crosses the axis, the stability vanishes. In other words, the ship will, without any force tending to upset her, go farther and farther away from the upright and tend to "turn turtle." This limiting angle is called the *range of stability* for the given conditions of displacement and position of center of gravity.

The method of calculation proposed by Barnes is conveniently applicable only to the investigation of the stability of a ship at a single given displacement. We know that ships are constantly varying in their displacement within wide ranges, and other methods of calculation have been adopted by which, with a series of curves, the curve of statical stability can be gotten out for any given displacement. There are a large number of such methods, which can be found in the standard text-books. The method used in the U. S. Service is not given here as it is of considerable length, but may be found if desired in the "Instruction for Standard Ship Calculations," referred to before.

All these methods depend upon a choice of a position on the center line, which is considered temporarily as the position of the center of gravity for all displacements and axis for all inclinations. With this pole or axis and a fixed inclination of ship, the righting arms, or righting moments are obtained for a series of displacements. These righting arms, or righting moments, plotted as ordinates with the corresponding displacements as abscissæ, give the curve for this inclination. Similar curves for a series of inclinations are plotted on the same diagram, forming what is known as the *cross curves of stability*. These are shown in Fig. 30, the cross curves of stability of the *Kearsarge*. The axis is taken at 24 feet above the bottom of keel or base.

There will be noted a series of curves marked 10 degrees, 30 degrees, 40 degrees, etc. These curves are the cross curves just referred to.

Suppose it is desired to know, with the cross curves, the curve of statical stability for any given displacement, say for a condition

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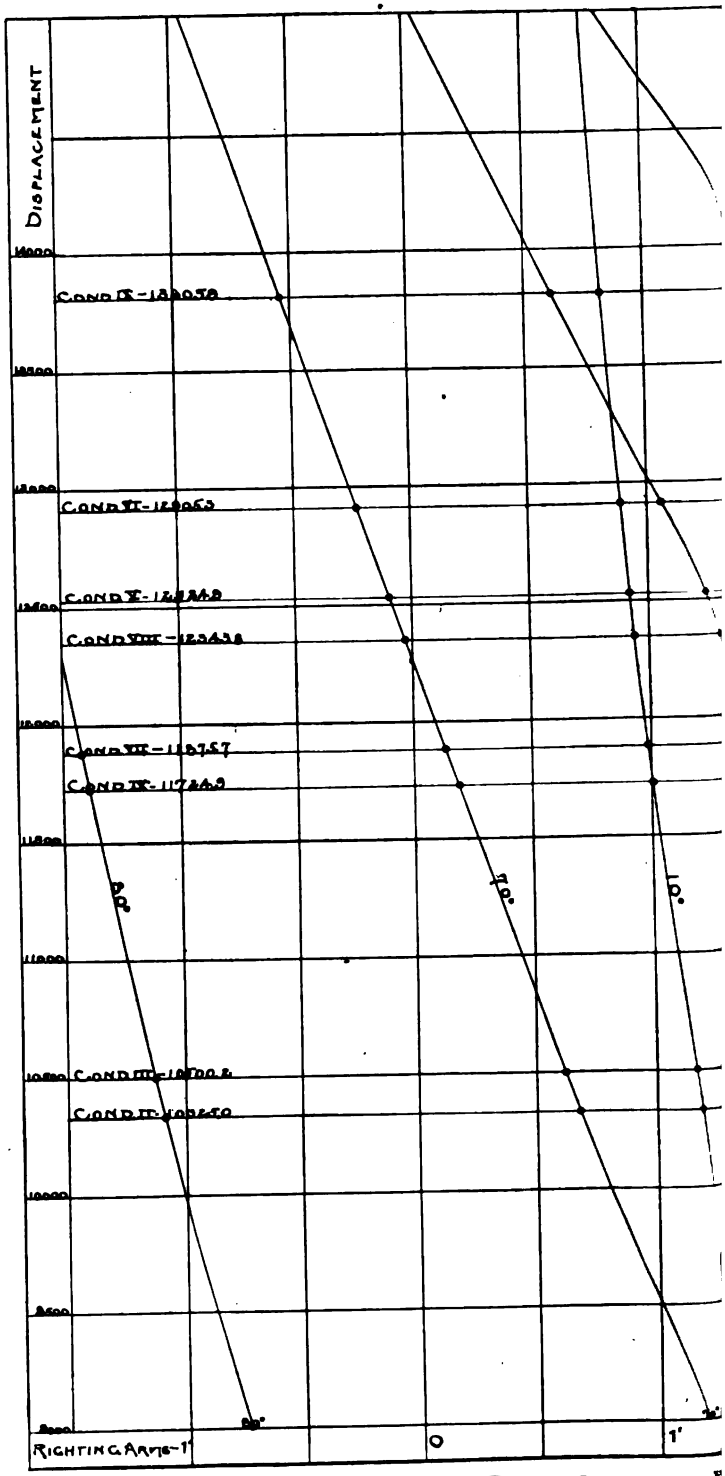

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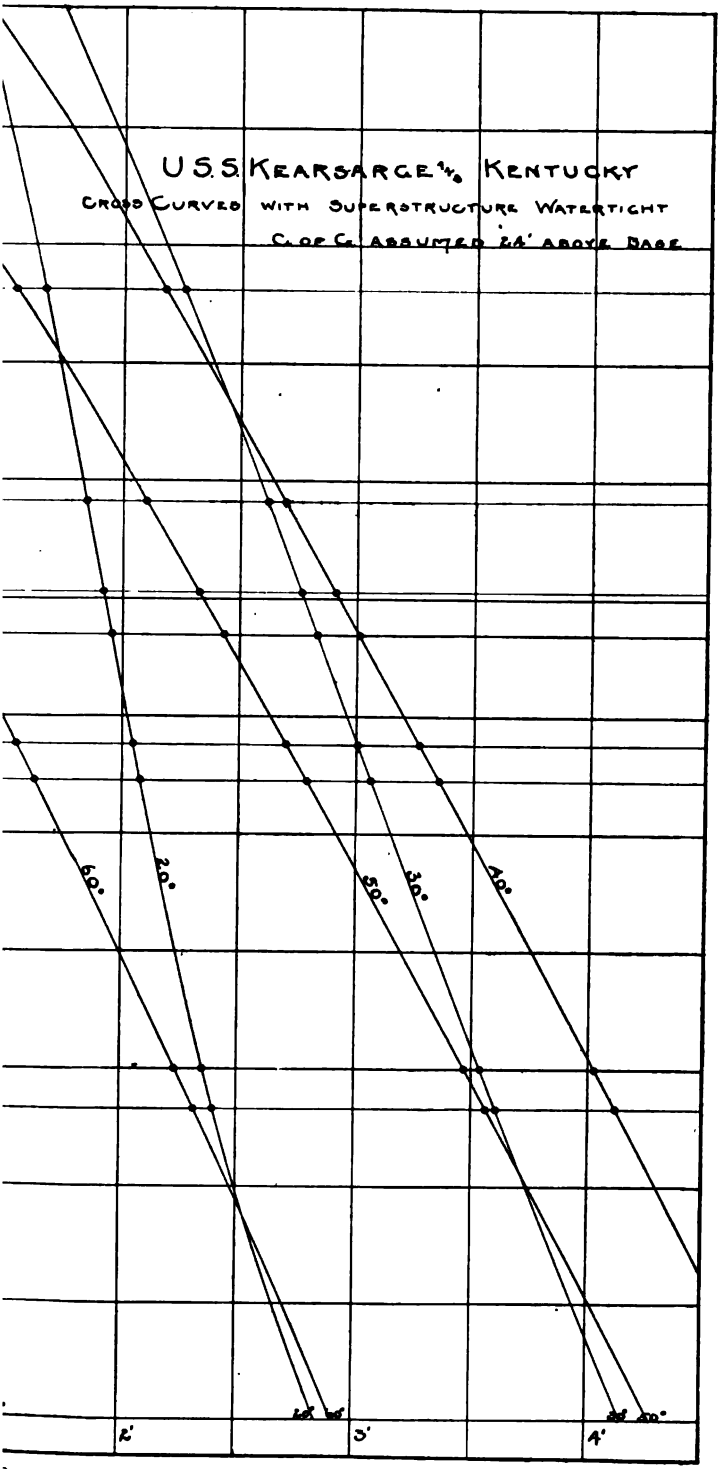

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with the ship complete with armament, ammunition, water in tanks, and machinery, and normal coal, corresponding to a displacement of 11,725 tons. Take on the cross curves a vertical line (indicated as Cond. IV—11,725 tons), and corresponding to each inclination, we note the intersection of the corresponding cross curves. If now there be laid off on an axis, to suitable scale, these angles of inclination, and ordinates erected which equal the distance from the line, *o*, to the respective curve intersections, multiplied by the weight of ship, we would obtain a curve of statical righting moment for a position of the center of gravity 24 feet above the base, that being the assumed position of the axis for our cross curves; this has then only to be corrected in a manner already indicated, by taking the distance of the center of gravity from the axis and multiplying it by the displacement and by the sine of the angle of inclination, adding it to the righting moment obtained from the cross curves if *G* is below the axis, and subtracting it from the righting moment if *G* is above the axis. There will thus be obtained a curve of righting moments for the actual position of *G*, and we have only to divide the righting moments by the displacement to obtain the righting arms. In other words, the same curve of the statical stability, read with a suitable scale, may be considered either as the curve of righting moments or the curve of righting arms.

In the case of the *Kearsarge*, the actual center of gravity for the condition just considered is 1.44 feet above the axis, so that we would have to make a correction, subtractive from the moment obtained by the diagram, of 11,725 $\times$ 1.44 $\times$ the sine of the angle.

It is evident that, for any other condition of displacement and position of center of gravity, by the use of these same cross curves of stability and in a precisely similar manner, a new curve of statical stability for the given set of conditions may be obtained. There are shown in Fig. 31, drawn to a large scale, such a series of curves of statical stability for the *U. S. S. Kearsarge*, under eight different conditions:

Condition No. IV is that for which the method of obtaining the curve has been explained in detail.

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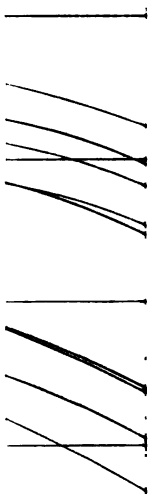

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It may be remarked concerning these curves that the position of the maximum righting lever is, in all cases, nearly 30 degrees, and that the range of stability varies from 46.2° to 53°. A consideration of these curves, or of any similar curves of statical stability, will at once show why the metacentric method is limited to small inclinations in its application. It has been stated that, in the application of this method, the fixed point called the metacenter was that at which the verticals through the center of buoyancy for each inclination all met. As a matter of fact, at comparatively small inclinations, this is not even practically so.

Considering the actual condition of the *Kearsarge* when the inclining experiment to determine the position of her center of gravity was made, we find that the ship then displaced 11.099 tons. The actual degree of inclination obtained, from which the center of gravity was calculated, was about 2¾°. For such an inclination, the intersections of the verticals through the centers of buoyancy are very accurately at the metacenter.

When, however, the ship is inclined over to an angle of 30°, the vertical through the new center of buoyancy no longer intersects the center line at the point, M, but is appreciably below it, and the righting arm, GZ, for this inclination of 30° is materially less than it would have been if the vertical through the center of buoyancy, B_1, passed through the metacenter, M. It may be remarked that the righting arm for a given inclination by the metacentric method was $MG \sin \theta$. If this method were applicable to all inclinations, the curve of statical stability would be a curve of sines, and the maximum righting arm would be equal to MG at 90° of inclination (in other words, when the ship is on her beam ends), and the range of stability would be 180°. How far this is from the truth is seen at once on an inspection of the actual curves of statical stability of the *Kearsarge*.

The principal influences determining the forms and range of the curves of statical stability in a ship may be stated as, *1st*, freeboard, including in this the reserve of buoyancy; *2d*, the beam; *3d*, the vertical position of the center of gravity, and, *4th*, the vertical position of the center of buoyancy when the ship is upright.

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The freeboard and beam are of course relative, and are to be considered with relation to the draft of water. The vertical position of the center of gravity is to be considered with reference to the total depth of the ship, and the center of buoyancy with reference particularly to the mean draft.

A high freeboard conduces to a great range of stability. The maximum righting arm is generally obtained shortly after the deck edge is immersed. In the case of the *Kearsarge,* with a mean draft of 23 ft. 10½ in., this immersion occurs at an angle of about 18°. If it be noted that the maximum righting lever of the *Kearsarge* occurs at an angle of about 28 degrees, it will be seen how great an importance the immersion of the deck edge has upon the stability. An inspection of Figs. 28 and 29 will also show why this is, for the points g_1 and g_2, which have been spreading farther and farther as the wedge grows larger, will come in towards the center again, and the distance h_1h_2 will diminish rapidly. At the same time the deduction from the righting arm, due to the position of the center of gravity above the center of buoyancy, will become greater and greater.

Thus is seen the importance of freeboard and the reserve of buoyancy. The reserve of buoyancy means the volume and corresponding available buoyancy of the part of the ship not immersed, but which may be made watertight. In most vessels this enclosed part is limited by the upper deck, although in some vessels there are additional watertight enclosures above that deck which are to be taken into account. It is evident that, if this part of the ship is watertight, additional weight could be placed on the ship equal to this reserve of buoyancy before she would sink beneath the water. The sum of displacement and the reserve of buoyancy is thus the total floating power of the ship considered as a watertight shell.

If then, the center of gravity remains approximately in the same position relatively to the base, with a high-freeboard vessel as with a low-freeboard vessel, the deck edge will go under only at a much greater inclination, and the angle of maximum righting lever will be correspondingly increased. It may be added that a similar extension occurs of the total range of stability. It is for this reason that high-freeboard cruisers, and passenger vessels of the merchant mar-

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ine, need, and are usually given, less initial stability than vessels of low freeboard.

The influence of the beam is largely on the initial stability for reasons that have been explained in the earlier part of this work, and this influence will continue very predominant until somewhat after the deck edge has been immersed. The metacentric height will be increased, and the relative deduction for the height of the center of gravity over the center of buoyancy will not be so great. The effect of the great beam will, however, be greatly diminished as the angles of inclination grow larger and the total range of stability is, in general, comparatively little increased.

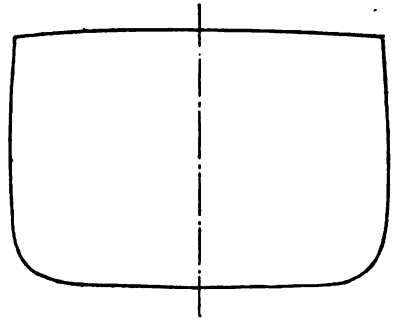

FIG. 32.

As to the effect of the vertical position of the center of gravity, it is clear that raising the center of gravity of the ship one foot, for instance, will decrease the righting arms by one multiplied by the sine of the angle of inclination, and, by just such an amount, would reduce the maximum righting arm and reduce correspondingly the range of stability. It will also be seen that the effect of adding water-ballast, which, as has been stated, almost invariably lowers the center of gravity, will usually produce an increase in the maximum arm and in the range of stability; providing, that, as must be carefully looked into, the water-ballast tanks are completely full.

The effect of a full under-water section, as in Fig. 32, is to lower the center of buoyancy. As the metacenter is measured

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up from the center of buoyancy, this has the effect of lowering the metacenter with reference to the base. The center of gravity of the ship will also be lowered, but usually not to the same extent as the metacenter. The net result then may be considered to be that in the ships with a V-shaped section (Fig. 33), where the center of buoyancy is higher, the initial stability and the maximum righting arms will be increased, but the range of stability will be less affected and may be decreased. It is partly for this reason that sailing vessels and yachts are usually given a much sharper dead rise than steamers.

The influence of these different conditions will be evident on examining the curves of stability of the *Kearsarge*. Here is a ship

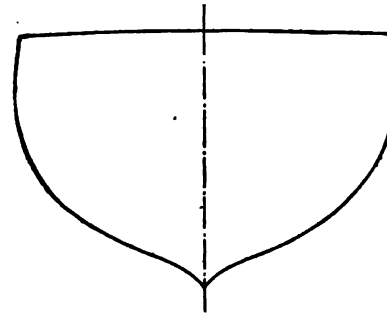

FIG. 33.

of comparatively low freeboard in which the center of gravity of the ship is high, owing to the weight of the guns and armor placed high up in the vessel. The beam is great. Under these circumstances, all the curves show a good initial stability, but the maximum righting lever occurs at an angle of about 30° and the range of stability varies from 46.2° to 53°.

Let us compare with this ship the stability curves of the *Alabama* (see Fig. 34). The general arrangement of weights in the two ships is somewhat similar, but, owing to the condition of a deck forward and the consequent raising of the forward turret, the center of gravity is raised slightly higher above the base in most conditions. The important point of difference in the hull design is, however, that the *Alabama* has, in lieu of a comparatively small

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superstructure, an upper deck extending from the stem two-thirds of the way to the stern. It will be observed how the greater freeboard and reserve of buoyancy increase the range of stability. The increase would be greater but for the effect of the rise of the center of gravity. It will be observed that the maximum righting arm is at an angle of about 8° greater than for the *Kearsarge,* and that there is a similar increase in the maximum range of stability.

In comparison with these ships, examine the curves of the *Raleigh* (Fig. 34), a vessel with comparatively small metacentric height, position of the center of gravity medium but rather higher than in most cruisers of a similar character, and fairly high freeboard. Here the maximum righting arm occurs at an angle in the neighborhood of 40°, and the range of stability varies from 60° to 71°. Here it is seen that, notwithstanding the very much smaller metacentric height of the *Raleigh,* and her much less ratio of beam to depth, her freeboard gives her the advantage of the *Kearsarge* in the position of maximum righting lever and in the range of her stability. But note the difference on the *Raleigh* of the smaller initial stability (that is to say the comparatively high position of the center of gravity), which gives her less range of stability than is the case with a great number of cruisers.

There are, in Figs. 36, 37, and 38 a series of the curves of statical stability of a number of our ships:

The first of these figures (36) is for vessels in the light condition, without provisions, stores, coal, or ammunition, boilers being at the steaming level; the second (37), for vessels in normal condition, with normal supplies of feed water, stores, ammunition, and coal (the lower bunkers full); the third (38), for vessels in full-load condition, with full allowance of stores, feed water, and ammunition, and with bunkers full. The great contrast between the different kinds of ships will be seen at once. No. 1, the curve of the *Arkansas,* a monitor, has a very great initial stability and a great righting arm, but a few degrees of inclination puts the deck edge under, and her stability decreases with great rapidity, vanishing at a comparatively small angle. Protected

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cruisers and gunboats, with very high freeboards and with fair metacentric heights, like the *Chattanooga* and *Dubuque*, have a range of stability approximating 90°, or exceeding it. The torpedo-boat destroyer *Faragut* is a case of a vessel in which, relatively speaking, the beam and the freeboard are both high. It also has, for such a small vessel, a good metacentric height. It will be observed that the range of stability is very great indeed, the righting arm remaining in all cases very considerable, even at an inclination of 90°.

Stability in Battle.

In most modern warships the center of gravity is usually near the load waterline, or slightly above, usually being higher when the ship is light than when it is loaded. Hence, it may be said, in a general way, that in most of our warships, the addition of small weight decreases the initial stability, if it is placed above the load waterline. An application of this remark is in preparing a ship for action. Getting rid of the top hamper by either placing it below under the protective deck, or by dropping it overboard will, in general, tend to increase the initial stability of the ship, which is desirable in the circumstances of action. An example of this is the boats of the ship, which, on any ordinary cruiser or large vessel, will usually weigh from 15 to 30 tons. They are invariably and necessarily placed high on the vessel, and, if they can be dropped overboard, it will give just that proportional additional metacentric height to the ship, which corresponds to their position above the center of gravity, which, as has been stated, will usually be near the load waterline.

If, as may sometimes be the case, the ship is considered a "tender" one, it may be advantageous, before action, to fill the compartments of the double bottoms with water. But this must be very carefully considered before it is undertaken. While, as has been stated, such an addition of weight to the bottom of the ship will almost invariably increase the initial stability, it will have several disadvantageous results. It is presupposed, and must be carefully attended to, as explained above, that the water let into the double bottoms completely fills the double-bottom

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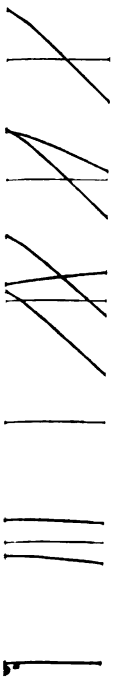

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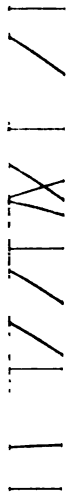

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compartments; otherwise, the partial filling of the bottoms may, instead of increasing the initial stability, materially diminish it. The first disadvantage of a full double-bottom compartment is, in case of an explosion of a torpedo or a mine under the bottom, that the solid water contained transmits the shock to the inner skin, which will thus be much more readily ruptured (causing the possible sinking of the ship) than if the compartments were only filled with air, in which the gases due to the explosion could expand. The second consideration is that the addition of a considerable quantity of water in the bottoms materially increases the draft, thus lowering the protective deck relatively to the outside water and increasing the displacement. The first result may, in case of waterline damage, allow a much greater volume of water to penetrate on top of the protective deck, which may make the difference between the ship "turning turtle" or not. The increase of displacement will result in a corresponding decrease of speed. Thus, for the circumstances of action, it will be necessary for the commanding officer to carefully consider the advantages and disadvantages of the admission of water into the bottoms, and to decide intelligently on this subject, he must be acquainted with the qualities of his ship and all the attendant circumstances that are liable to occur. It may be said, in conclusion, that if the weather is rough and a heavy sea running, it will, in general, be desirable for him to have a greater stability than if the sea is perfectly smooth.

Another question that may arise in preparing for action is the distribution of coal. Nearly all modern vessels have both upper and lower bunkers. The upper bunkers are above the protective deck and are supposed to act as a partial protection against the enemy's projectiles. Not only is this so, but the coal itself acts to exclude just such an amount of water and to prevent its having a free surface. From experiments made by the British on the *Resistance,* it was found that loose coal 20 feet thick would stop a 6-inch projectile, and 30 feet would resist an 8-inch gun. In other words, 2 feet thickness of coal was about equal to 1 inch of wrought iron in resistance. The explosion of shells in the coal was found to have little effect in displacing it, and

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the coal was not set on fire by them. At the same time, the metacentric diagram considered will show that, if the coal is in great part carried in the upper bunkers, the initial stability is usually much less than when the coal is in the lower bunkers.

Effect of Shifting Weights.

The effect on stability and trim, of shifting weights, comparatively small in relation to the displacement, has been treated in Chapter IV. If these weights assume considerable proportions relatively to the displacement, such as to cause very considerable inclinations or changes of trim, the metacentric method is no longer applicable. If such weights are added on the middle longitudinal plane of the ship, they will not (unless they render the ship unstable by reason of the rise of the center of gravity) cause it to be inclined. But, unless they are in the vertical through the center of gravity of the load plane, they will cause a change of trim. If they are not sufficiently far forward or aft to make a great change in the trim, such change may be calculated from the longitudinal metacentric height in the manner explained above. If it became necessary to discuss great alterations of trim, a diagram of the cross curves of stability, similar in its general type to that for transverse inclinations, would have to be constructed. It may also be remarked that the usual cross curves of stability are calculated for the normal trim of the ship, and any serious alterations of the trim will change the character of these curves to a considerable extent, the net result being, with the usual type of vessels, that this transverse stability will be diminished both in the righting arm and in range.

If, however, the change of the trim is not so great as to falsify materially the cross curves of transverse stability, they may be utilized to find the position of equilibrium of the ship at very considerable angles of heel.

The details of such calculations will not be gone into.

Without any actual damage to the skin of a ship, water may find its way into the interior through open ports or scuttles in the side, or open hatchways in the decks, the result being a more

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or less serious decrease of stability. Such occurrences are exceptional, but they have happened in ships caught by squalls of wind in comparatively smooth water. The British training ship *Eurydice* is an example.

The only thoroughly satisfactory way of making a complete investigation of the stability in a damaged condition, with free water surface, is an experimental method in which small-scale models of the vessel under construction are used. The manner in which these experiments are made and the results obtained treated to determine the stability in a damaged condition are explained in detail in a paper by Mons. L. E. Bertin in the Transactions of the American Society of Naval Architects and Marine Engineers for 1894.

The mathematical treatment of the curves of stability as determined by Mons. Bertin will not be gone into, but it is only necessary to state that, by the method developed by him, a very complete study of the stability in damaged conditions can be obtained.

It is remarked by Mons. Bertin, as the result of his investigations, that it is usually found that the danger of the vessel's upsetting was much greater than that of its sinking directly. In the modern type of war vessels with a protective deck this will be generally found to be the case. Such reports as are available as to the Battle of Tsushima indicate this result.

Let us consider how the naval architect endeavors to prepare his vessel for action so as to prevent this "turning turtle." It may be remarked, before proceeding further, that the subdivision of a man-of-war can be rendered much more elaborate than of a merchant vessel. This is, moreover, in the man-of-war, a fundamental necessity, as is also the watertight deck, called the protective deck, to protect the vitals of the ship from damage by explosion of shell above the water. It is a necessity of the case that this deck should be complete and have as few holes in it as possible. It is accordingly made water-tight. This protective deck is situated below the normal waterline at the sides, and, at the middle, is sometimes above the normal waterline and sometimes below it.

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Above this is always another deck, usually a few feet above the waterline, which, in our service, is called the *berth deck.* This horizontal slice of the vessel in the waterline region has come to be known as the *raft-body.*

As projectiles are most likely to admit water above the protective deck in the space of the raft-body, the additional load of water will be usually high. At the same time, the waterline area to provide initial stability will be decreased in a number of compartments in communication with the sea; while the protective deck, if it remains intact, will prevent the water from penetrating into the lower part of the ship. It will thus usually arise that the stability vanishes before the floating power of the ship is very seriously impaired. In a merchant ship no such deck as the protective deck exists, and the designer is free to make his watertight subdivision by multiplying athwartship bulkheads.

This latter method, considered from the point of view of the stability and flotability of the ship, careful investigation will show to be the best for that purpose. But, in a man-of-war, there are limitations which necessitate the multiplying of the longitudinal bulkheads, and, as these longitudinal bulkheads have to exist, they are utilized, as far as possible, to multiply the number of watertight compartments. The great necessity for longitudinal bulkheads exists principally in the fact that it is very desirable to group the machinery and coal in several units, so that, if a certain number of them are paralyzed in action, the remainder will still be available to permit the ship to retreat out of action, or even possibly to vanquish the enemy, more disabled than itself.

The longitudinal center-line bulkhead of a ship has been a matter of great controversy since the cellular subdivision of ships became established as current practice. While space does not permit entering into a detailed discussion of the considerations involved in the stability curves, it may be said, as a result of such investigations, that a longitudinal center-line bulkhead forming compartments in which water is free is not advantageous, if it be practicable to utilize the same weight in more closely spacing the transverse bulkheads in the ship. It is, however, as has been

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said, sometimes necessary in order to isolate the machinery into independent groups.

The force of circumstances has therefore generally compelled the designers of ships to make a raft-body, and endeavor by all means in their power to prevent the water from penetrating into the ship below protective deck. The chief danger to be guarded against, therefore, is that of "turning turtle." This has been accomplished in two principal ways: One by the use of cofferdams, and the other by the use of extensive cellular dubdivision in the raft-body. In the U. S. Service, the cofferdams have been placed where, it is believed, they should be, that is, just inside the outer skin of the ship, and they have been filled with an obturating material which has been the corn-pith cellulose. In the British service, the cofferdams are usually placed around the hatches, and are kept empty, the idea being principally to prevent the water, when admitted on the deck, from penetrating below, by stuffing places between the two walls of the cofferdams with any material that comes handy to stop the leak.

The second method is by extensive subdivision of the raft-body. It is assumed that, if the projectiles penetrate, only a small number of cells will be broken into, either by holes made directly by the projectile, or by the explosion of shell. The reduction of the waterline area will thus be limited and will not be sufficient to destroy the initial stability.

A consideration of all that has gone before shows us the immense importance of the watertight subdivision of a man-of-war which is liable to damage in action. Such watertight subdivision, however, may be rendered nugatory through the multiplicity of openings through supposedly watertight bulkheads, such as doors or openings for ventilation. The very great importance of this matter is sometimes not realized, and the tendency is to multiply the number of doors and other openings. It has been known to occur that small holes have been cut through watertight bulkheads without any provision whatever for stopping them, thus reducing the efficiency of the cellular subdivision.

It is therefore urged upon all those having charge of such mat-

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ters on ships in service to prepare carefully a list of the openings, doors, scuttles, valves, etc., which can be kept closed in action, and others, which, after consideration, must be kept open in action. It is of course essential that there should be a reasonably free communication in certain parts of the interior of the ship during action. It will therefore always be necessary to have a number of watertight doors and scuttles open in action, but the number of these can be materially reduced by a careful consideration of the plans of the vessel and the study of results obtained in drills and exercises during times of peace.

Nor are such considerations to be neglected in ordinary cruising, and it is urged upon all who go to sea in ships to study how they maintain the maximum of watertight subdivision at all times. It should be looked after that watertight doors and other openings not actually in use for passage or ventilation, especially in the raft-body and below the protective deck, are kept closed and closed *watertight.* When such precautions are observed, the commanding officer may feel reasonably sure that no such disaster will overtake his ship as that which occurred to the ill-fated *Victoria.*

Dynamical Stability.

The dynamical stability of a vessel, at any angle, is the work done upon that vessel in heeling her over to that angle = weight of ship × vertical separation of C. G. and C. B.

Moseley's formula for dynamical stability:

Refer to Fig. 28 (the statical stability figure). Here, the ship being inclined at an angle θ,

B has moved to B^1 or been lowered by an amount $= B^1Z - BG$

G has remained constant in location,

If W = weight of ship

(1) Dynamical stability $= W\ (B^1Z - BG)$

But (2) $B^1Z = B^1R + RZ = B^1R + BG \cos \theta.$

Let v = volume of immersed or emerged wedge

V = volume of ship's displacement

Then $v\ (gh + g^1h^1) = V \times B^1R$

(3) $B^1R = \dfrac{v\ (gh + g^1h^1)}{V}.$

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Therefore, from (2) $B^1Z = \frac{v(gh + g^1h^1)}{V} + BG \cos\theta$

Therefore, from (1) Dynamical stability $= W\left(\frac{v(gh + g^1h^1)}{V} - BG(1 - \cos\theta)\right)$.

The dynamical stability of a ship at any given angle is equal to the area of the curve of statical stability to that angle, i. e., dynamical stability is the integral of the statical of the statical stability. The demonstration of this, being somewhat intricate, is not given; but from the above statement it will be seen that not only the range of the statical curve, but also the area, is of importance as indicating the work to be done to heel the ship.

For further treatment see:
Stability of Ships, Sir E. J. Reed.
Theorie du Navire, E. Guyon.
Theorie du Navire, Pollard & Dudebout.

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At G, therefore, we may introduce two equal and opposite forces, P, parallel to the other force on rudder. Then we have acting on the vessel:

(1) A couple, force, P, arm GD tending to turn,

(2) A force, P, acting through G in line EG.

We may further resolve this (2) into

(3) A force, $EF = P \sin \theta$ parallel to keel and opposite to line of advance and therefore tending to retard her motion.

(4) A force, $FG = P \cos \theta$ perpendicular to line of advance, tending to cause sidewise motion.

Heeling Due to Putting Over Rudder.

When the rudder is first put over, the force, P, tends to cause

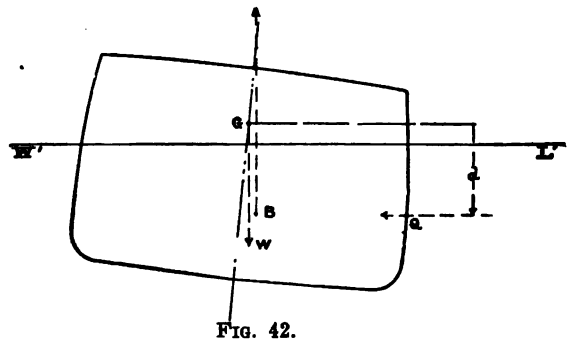

FIG. 42.

heeling inwards. This is especially noticeable in destroyers and other vessels having relatively large rudder areas.

In large ships, this inward heeling is generally followed by an outward heeling, due to centrifugal force setting outward through the C. G. of ship, which is generally above the center of pressure of water on the outside, called *center of lateral resistance*. This outward heeling tendency is resisted by the stability of the ship. This may be illustrated by Fig. 42.

In the above are indicated the forces acting after the vessel has started turning, independent of the forces on the rudder.

The angle of heel which a vessel will take up is approximately

$$\text{Sin } \theta = \frac{1}{11} \times \frac{d}{GM} \times \frac{V^2}{R}.$$

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Where d = vertical distance between C. G. of ship and center of lateral resistance

GM = metacentric height (transverse);

V = speed in knots on turning circle;

R = radius of turning circle in feet.

From this equation it will be noted that the heeling on the circle varies:

(1) *inversely* as metacentric height;

(2) *directly* as *square* of speed;

(3) inversely as radius of circle.

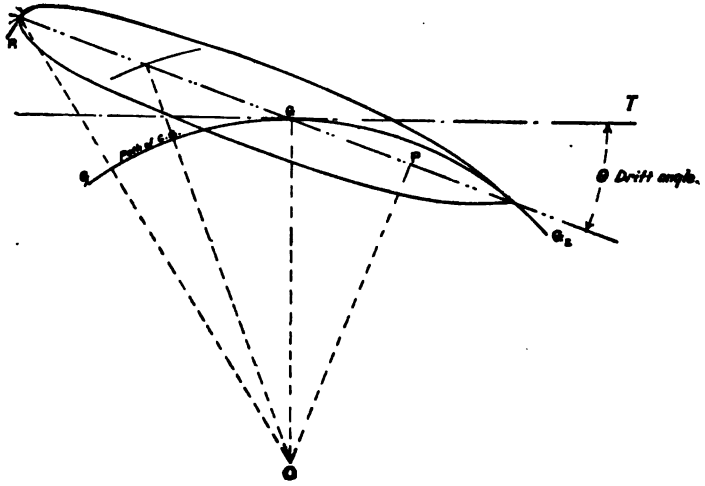

FIG. 43.

It is often found in destroyers and torpedo boats where the distance, d, above, is not great, that the outward heeling tendency due to centrifugal force is overcome by the inward heeling tendency due to pressure on the rudder whose center of pressure is below the center of lateral resistance. Care should be taken in such vessels not to right the helm too soon in turning, or the vessel may give a dangerous list outboard.

Drift Angle and Pivoting Point.

When a ship is turning in a circle, the fore and aft center line points inside the circle; therefore, the propelling force is delivered

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in a direction oblique to the motion of the vessel. This is a further reason for reduction of speed of a vessel in turning.

The ship being at any instant as shown (Fig. 43).

G_1GG_2 being path of C. G.

O being center of this path

Draw GT tangent to path at instantaneous position of G,

Then PGT is *drift angle;*

From O draw perpendicular to longitudinal center line of ship. Then P is *pivoting point* at drift angle $= \theta$.

The motion of any point in the ship is instantaneously in the direction of the tangent to the circle in which that point is turning.

All points abaft P will, relative to P, move to port.

All points forward of P, will, relative to P, move to starboard.

Path of Ship in Turning.

The rudder of a ship being put over, the ship begins to turn in a spiral path. By the time she has turned 8 points, the path is approximately circular.

The distance from the position at which the helm is put over, to position at which she is moving perpendicular to her original course, is called the advance.

The distance from the original course to the position where she has turned through sixteen points is called the Tactical Diameter.

The turning of a ship is influenced by:

(1) Time of putting helm over.
(2) Helm angle.
(3) Size of rudder.
(4) Moment of resistance of underwater body to turning.
(5) Moment of inertia of ship.

CONSIDERING (1) With modern steering gears, this is a very short time. This time is reduced by the use of balanced rudders, bringing the center of effort closer to the axis of rotation and offering but small resistance to being put over.

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CONSIDERING (2) Stops are usually placed, in the U. S. Service, limiting the helm angle to 35°. The tactical diameter varies roughly inversely as the helm angle, so a larger tactical diameter may be obtained by using a smaller helm angle.

CONSIDERING (3) As pressure, P, depends on size of rudder, this is obvious. It is usual to express the rudder area as a fraction of the area of immersed middle-line plane of the ship. The following table indicates ordinary values of this ratio:

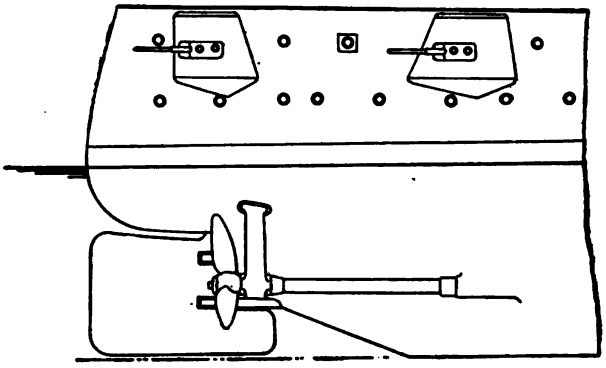

FIG. 44.

Battleships	1/37
Large cruisers	1/45
Small cruisers	1/41
Destroyers	1/31

CONSIDERING (4) Resistance to turning depends on shape of underwater body and the position of pivoting point. This is generally well forward.

As the moment of resistance offered by any portion of the surface varies roughly as the cube of its distance from pivoting point, times cosine of the angle which it makes with the vertical,

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the flat portions at after end offer the best resistance to turning. This explains the reason for cutting away the after end of vessels to allow of under-hung balanced rudders, as shown in Fig. 44.

A short ship will turn more rapidly than a long ship.

A ship trimming more by stern than usual will have larger tactical diameter than when in her normal condition.

CONSIDERING (5) A ship with heavy weights at bow and stern will turn more slowly than one whose weights are concentrated amidships, and will return to her original course more slowly when once turning.

The usual values of tactical diameters for vessels, of various classes, in the U. S. Service, both engines operating at full speed ahead, are as follows:

	Tactical Diameter (about).
Battleships (length about 380 feet)	398 yards
Armored cruisers (length about 510 feet)	615 "
Protected cruisers (length about 320 feet)	610 "
Monitors (length about 250 feet)	220 "
Torpedo-boat destroyers (length about 250 feet)	390 "

The turning of twin-screw ships may be greatly aided by running the engine on side towards which rudder is put, ahead, and on the other side, astern.

Turning trials are carried out on final trials and after commissioning of vessels. The instructions for conducting these trials are quoted herewith:

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TURNING AND MANEUVERING TRIALS.

Date, ...; Place, ...; Direction of wind, ...; Force, ...

Condition of sea, ... ; Ship's draft: Forward, ...; Aft, ...; Mean, ...

Maneuvers to begin with all screws going ahead full speed and with full headway.	Ship's head before turning.	Time to put helm over.	Helm angle.	Heel of ship corrected for initial list.	Number of revolutions on straight.	Number of revolutions on curve.	Tactical diameter, yards.	Advance at 180 degrees.	Time to complete half circle.
Hard astarboard.....									
Hard aport.....									
Hard astarboard, port screw stopped									
Hard aport, starboard screw stopped.....									
Hard astarboard, port screw full speed astern.....									
Hard aport, starboard screw full speed astern.....									

From full speed ahead, time from signal "full speed astern" to entire loss of headway,.....; speed,.....; advance, ...

Using both screws ahead: Revolutions, ...; speed, ...knots.

Using one screw ahead: Revolutions, ...; speed, ...knots; helm angle, ...

NOTE.—See appended instructions for obtaining tactical data. If not followed, state method employed.

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NOTE.—The tactical diameter will be observed when practicable by the following method:

Preparations.

1. Two (2) poles, weighted at their lower ends to float upright; to be immersed to the mean draft of the ship and to show 6 feet above the surface of the water. On each pole will be placed a flag 3 feet square, of red and yellow bunting, in three equal and vertical stripes, yellow in the centers. Boats' spars lashed together may be used for these poles, as they will be recovered after the trials.

2. Two fixed plane tables or peloruses for relative bearings of the distant object. These shall be mounted, so that from one or the other every point of the horizon is visible, preferably on the ends of the bridge.

3. Two theodolites or other horizontal circles mounted forward and aft on the middle line of the ship, and as far apart as practicable; the distance between them to be accurately known. These instruments should be of considerable accuracy, and should determine the angle between the floating pole and the middle line of the ship within a maximum error of 10 seconds of arc. In slow-turning ships an error of 1 second in either angle will produce an error of 1 yard in the tactical diameter.

The Range Finder telescopes are admirably adapted for this purpose.

Observations.

1. Select a place where the water is of sufficient depth, the tidal movement (if any) unobstructed and uniform, and a permanent and visible object—lighthouse, tower, or building—not less than 6 miles distant.

2. Have a pole over the side abreast the foremast (port side for starboard helm, starboard side for port helm) slung with a slip rope or squilgee so that it will fall clear of the hull.

3. Stand on a straight course with the distant object about abeam. At a blast of the whistle, slip the pole, put the helm over, and take a relative bearing of the distant object.

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4. Move the plane-table pointer through 16 points, and when the distant object comes on, sound the whistle a second time, when the observers at the instruments at the ends of the ship will carefully take the angles between the floating pole and the fore and aft line of the ship. These angles must be taken accurately, simultaneously, and on the instant; otherwise they will be of no value.

5. The data for determining the tactical diameter has now been obtained. Having two angles and the included side, solve the triangle, which gives the distance of the floating pole from the forward station of the ship when the half circle was completed. With this distance as hypothenuse and the angle of the floating pole forward of the beam as one of the oblique angles, solve the right triangle. Let A represent the side adjacent, B the side opposite, and C the half beam of ship; then

The sum of A and C will equal the tactical diameter or "transfer" of the ship at 180 degrees.

B will equal the "advance" for 180 degrees.

The sum of A, B, and C will practically equal the "advance" for 90 degrees.

6. For subsequent determinations stand on and turn, and approach the pole either on the same course, as at first, or its opposite (that is, with the distant object abeam). Pass as close to the pole as possible, steering a steady course, put the helm over when it is abreast the forward station, and estimate its distance at that time from the ship, which add to the half beam. Proceed as before.

7. The second pole is prepared as a reserve. If desirable it may be dropped on the second turn a mile or more distant from the first, and the two employed alternately, which will diminish the time necessary for a long series of trials.

Second Method.

(To be employed when the tactical diameter is greater than 800 yards.)

1. Place one of the poles in the water, and, standing off to some distance, turn and steer for it on a course which shall bring the

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distant object about abeam as before, and which shall cause the ship to pass the pole at a distance of about half the tactical diameter. When the pole is exactly abreast the forward station, sound the whistle, angle upon it from the ends of the ship, put the helm over, and take the bearing of the distant object. At 16 points (determined by bearing of the distant object as before) angle again upon the pole.

2. With the data obtained determine the distance of the pole from the forward station at the first and second positions. Let the first be called *D*. Employ the second as before; then

The sum of *A* and *D* equals tactical diameter.

B equals "advance" at 180 degrees.

The sum of *A*, *D*, and *B* practically equals "advance" at 90 degrees.

The half beam is eliminated, as the distance of the pole on both sides is measured from the middle line of ship.

NOTE.—Employing relative bearings of a distant object avoids any dependence upon the compass, and beginning evolutions with that object abeam brings the ship at the end of the half circle substantially upon the same line of bearing and obviates error due to parallax. With an object six miles distant a change of bearing of 1 degree corresponds to a change of position of 210 yards.

Employing a floating pole upon which the tidal influence will be the same as upon the ship itself, eliminates the effect of that influence.

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CHAPTER VII.

ROLLING AND OSCILLATIONS.

The main object in studying the question of oscillation of ships is to ascertain the elements governing or affecting the rolling motions of a vessel in a seaway, so that her probable safety at sea may be secured in her design.

No attempt will be made to go into the theory of waves or oscillations, but the following practical facts, of use to the seagoing officer are stated:

Determination of the period.—If the period be denoted by T, the metacentric height by m, and the radius of gyration about a longitudinal axis through her center of gravity by k—

$$T = \pi \sqrt{\frac{k^2}{gm}} = .554 \sqrt{\frac{k^2}{m}}.$$

A fair approximation to the *still-water* or *"natural" period* of oscillation for a new ship is given by this formula. The metacentric height is determined for a warship as one of the particulars of the design; and the distribution of the weights is known, so that the moment of inertia can be calculated about the assumed access of rotation passing through the center of gravity. This latter calculation is laborious, the weight of each part of the structure and lading having to be multiplied by the square of its distance from the axis; but with care it can be performed with close approach to accuracy. Calculations of this kind are rarely made except in connection with novel types of ships for which thorough investigations are undertaken in order to be assured of their safety and seaworthiness.

The formula given for the period supposes rolling to be unresisted; but the influence of resistance is much more marked in the extinction of oscillations than it is in affecting the period, and this accounts for the close agreement of estimates made from the formula with the results of experiments. Dr. Froude discov-

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ered that the period of the *Greyhound* remained practically the same, after exceedingly deep bilge-keels had been fitted, as it was without such keels.

Periods of various classes of warships.—Rolling experiments have been made on most classes of warships, and their natural or still-water periods have been determined. The following summary gives about the average values:

For small gunboats, torpedo boats, and small craft, the period for a single roll is from 2 to 3 seconds, these small periods being due to the radii of gyration consequent upon the small dimensions, and the necessity for securing a good metacentric height.

For the larger gunboats and smaller cruisers, periods of from 3 to 4½ seconds are common, and 4 seconds is a good average.

The larger armored cruisers average from 5 to 6 seconds, but some of the later swift cruisers have periods as high as 8 seconds, their metacentric heights being less than those of earlier types.

Among armored ships, the shortest periods are found in coast-defense ships of shallow draft, great proportionate beam, and large metacentric height. One of our monitors was found to have a period of 2.7 seconds only, and some of the French floating batteries have periods of 3 to 4 seconds. The earlier types of coast-defense battleships have periods of 5 to 6 seconds, and the larger seagoing battleships and armored cruisers, having less metacentric height and a large radii of gyration, range from 7 to 9 seconds.

Value of bilge-keels.—It has been determined that direct resistance is experienced by the comparatively flat surfaces of deadwoods, keels, bilge-keels, etc., hence it follows that resistance to rolling may be considerably influenced by fitting such appendages.

In fact the use of bilge-keels has become the most common means employed to increase resistance to rolling.

Number and arrangement of bilge-keels.—Warships and some classes of merchant ships are now commonly fitted with bilge-keels. Usually one such keel is fitted on each side, near the turn of the bilge, and carried as far forward and aft as may be convenient. In some cases, two keels have been fitted on each side,

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but there are objections to this arrangement. Two shallow keels have much less power in extinguishing oscillations than a single deep keel of area equal to the combined area of the other two; and there is difficulty, except in large ships, in placing two keels on a side sufficiently clear of each other, without the risk of emersing the upper one during rolling.

Effect of emersion of bilge-keels.—As regards the emersion of bilge-keels, it is necessary to remark that more or less violent blows or shocks are received by such keels as they enter the water again; and even when no structural weakness results, the noise and tremor are unpleasant. Therefore, in the U. S. Service, the bilge-keels are always so fitted that they are, at no point in the roll, likely to be emersed.

Size of bilge-keels.—Practical considerations usually determine the depths given to bilge-keels. Relatively deep keels require to be strongly constructed and attached to the hulls, since their extinctive effect on rolling is necessarily accompanied by considerable stresses on the material. In vessels of great size, the limit is fixed by the necessity for compliance with certain extreme dimensions fixed by the docks which the vessels have to enter.

Effect of "water chambers."—Other means have been devised for checking rolling, and for small oscillations, some of these are more effective than bilge-keels. But, on the whole, bilge-keels are the simplest and most effective means of limiting rolling motions which can be taken, in addition to those which lie in the power of the naval architect, in regulating the stability or the period of oscillation.

For certain classes of ships having large metacentric heights and comparatively short periods of oscillation, the plan of fitting a "water chamber" has been tried. H. M. S. *Edinburgh*, a central-citadel turret ship, with which very extensive experiments were carried out by the British Admiralty, may be taken as a typical case, having been fitted with a large "water chamber" about 7 feet high, 16 feet long fore and aft, and so arranged that its breadth could be the whole breadth of the ship, 67 feet, or made 51 or 43 feet. For small angles, the chamber gave greater extinctive effect

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than bilge-keels, but at larger angles, the bilge-keel had the greater effect. The chamber has never been used in practice to any extent, bilge-keels having been employed for the purpose.

Influence of free water in the hold.—It will appear that there are essential differences between the case of free water present in large quantities in one or more of the compartments of the hold of a ship, and that of the comparatively small quantities of free water carried for steadying purposes in the specially constructed closed chambers. Common experience proves that the presence of large quantities of free water in the hold of a ship affects her rolling, is always objectionable, and may be dangerous. The transference of water from side to side when the depth is considerable may be very rapid, and it will be obvious that the period of oscillation may be sensibly affected, while heavy blows may be delivered on decks, bulkheads, and other portions of the structure. Considerable damage has been done in some cases where water ballast has been carried in large tank compartments of considerable depth and where the surface has been left free either by leakage or by failure to fill the compartments.

Rolling amongst waves of synchronizing periods.—It is a matter of common experience that if a pendulum receives successive impulses, keeping time (or "synchronizing") with its period, even if these impulses individually have a very small effect, they will eventually impress a very considerable oscillation upon the pendulum. When a similar synchronism occurs between the wave impulses and the period of a ship, the passage of each wave tends to add to the range of oscillation, and were it not that the fluid resistance puts a practical limit to the range of oscillation, she would finally capsize.

Practical conclusions on unresisted rolling.—(1) Heavy rolling is likely to result from equality or approximate equality of the period of a ship and the half-period of the waves, even when the waves are very long compared to their height. (2) The best possible means, apart from increase in the fluid resistance, of securing steadiness in a seaway, is to give a ship the longest possible natural period for her still-water oscillations. (3) Changes of course and

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speed of the ship relatively to the waves affect the relation between the periods and may either destroy or produce the critical condition of synchronism. (4) Vessels having very quick periods, say 3 seconds or less for a single roll, fare better among ordinary large storm waves than those having periods of 4 to 6 seconds (which approximate very closely to the half-period of large storm waves), since the tendency in these very quick-moving vessels is to acquire a fixed oscillation, keeping their decks approximately parallel to the effective wave slope, though such a vessel would not be a steady gun platform. (5) For small seagoing vessels, for which the still-water periods are made short by the smallness of their moment of inertia, and the necessity for retaining a sufficient amount of stiffness, the effective wave slope is very nearly the upper surface of the wave, and their range of oscillation among large waves is practically determined by the wave-slope; but amongst smaller waves, approaching the condition of synchronism, these small vessels are worse off than very broad vessels of equally short periods, because the effective wave-slope for the broad vessel is so much flatter.

Pitching and 'scending.—The longitudinal oscillation of pitching and 'scending experienced by ships among waves must now be briefly considered. In still water these longitudinal oscillations do not occur under the conditions of actual service; and it is difficult, even for experimental purposes, to establish such oscillation, because of the great longitudinal stability of the ships. On this account we have little definite information respecting still-water periods for pitching, or the "coefficients of resistance" for longitudinal oscillations.

The formula for the period of *unresisted* pitching may be expressed in the same form as that given above for the period of unresisted rolling, where m is, in this case, the longitudinal metacentric height, and k is the radius of gyration taken with reference to the transverse axis through the center of gravity. The effect of the great longitudinal height more than counterbalances the effect of the increased moment of inertia for longitudinal oscillations, whence it follows that the period for pitching is usually considerably less than that for rolling, lying in many cases between one-half and two-thirds of the period for rolling.

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The existence of waves supplies a disturbing force capable of setting up longitudinal oscillations, leading to disturbances of the conditions of equilibrium as they exist in still water, and to the creation of accelerating forces due to the excess or defect of buoyancy.

The chief causes influencing the pitching and 'scending of ships amongst waves will be seen to bear a close analogy to what has been said in this regard about rolling, and will not require further explanation in detail. They are: (1) The relative lengths of waves and ships; (2) the relation between the natural period (for longitudinal oscillation) of the ship and the apparent period of the waves, this apparent period being influenced by the course and speed of the ship as previously explained; (3) the form of the wave profiles, *i. e.*, its steepness; (4) the form of the ship, especially near the bow and stern, in the neighborhood of the still-water load-line, this form being influential in determining the amount of the excesses or defects of buoyancy corresponding to the departure of the wave profile from coincidence with that line; (5) the longitudinal distribution of weights, determining the moment of inertia. In addition, fluid resistance exercises a most important influence in limiting the range of the oscillations. This resistance is governed by the form of the ship and particularly by that of the extremities, where parts lying above the still-water load-line are immersed more or less as the ship pitches and 'scends and therefore contributes to the resistance.

The most satisfactory and simple method of measuring the roll is by a movable batten and sighting on the horizon.

U. S. ships are generally fitted with some form of liquid clinometer, but all such apparatus are liable to certain errors.

Observations of lengths of waves.—From a scientific point of view, the observations made when a ship falls in with a series of approximately regular waves are most valuable. More frequently observations have to be conducted in a confused sea, successive waves differing from one another in lengths, heights, and periods, and occasional waves occurring of exceptional size as compared with their neighbors; but supposing a single series of waves to be

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encountered, the *lengths* and *periods* of successive waves can be easily determined if the speed of the ship and her course relatively to the line of advance of the waves are known. The method adopted will be briefly described.

Two observers (*A* and *B*, Fig. 45) are stationed as far apart as possible, at a known longitudinal distance from one another. At each station a pair of battens is erected so as to define, when used as sights, a pair of parallel lines at right angles to the ship's keel. The observers at both stations note the instant of time when a wave crest crosses their lines of sight; they also note how long an inter-

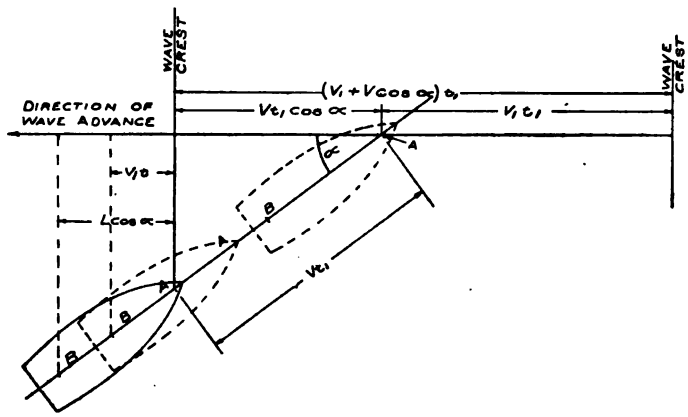

FIG. 45.

val elapses before the next wave crosses their lines. Comparing their records, they determine, (1) the time (say t seconds) occupied by the wave crest in passing over the length (L feet) between the stations; (2) the time (say t_1 seconds) elapsing between the passage of the first and second crest across either line of sight: this time is termed the "apparent period" of the waves.

Suppose a ship to be advancing at a speed of V feet per second *towards* the waves, her course making an angle of α degrees with that course which would place her exactly end-on to the waves. Then expressing the facts algebraically—

$$\text{Apparent speed of wave (feet per second)} = \frac{L}{t}.$$

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Real speed of wave (feet per second) $= V_1 = \left(\frac{L}{t} - V\right)\cos \alpha$.

Real length of wave (feet) $= (V_1 + V \cos \alpha)\, t_1$

$= L \cos \alpha . \frac{t_1}{t}$.

Period of wave $\frac{L \cos \alpha}{V_1} . \frac{t_1}{t} = \frac{L . t_1}{L - Vt}$.

If the ship is steaming *away* from the waves on the same course at the same speed, it is necessary to change the sign of V in the foregoing equation.

From the foregoing remarks it will be obvious that the simplest method of observing the lengths and periods of waves can be applied when a ship is placed end-on to the waves and is stationary. The true period and true speed of the waves can then be obtained by direct observation, and the lengths estimated.

When ships are sailing in company, a good estimate of the length of waves may be made by comparing the length of a ship with the distance from crest to crest of successive waves. Care must be taken, of course, to note the angle which the keel of the ship used as a measure of length makes with the line of advance of the waves; otherwise the apparent length of the wave may considerably exceed the true length.

Another method of measuring wave lengths consists in towing a log-line astern of a ship, and noting the length of line when a buoy atached to the after end floats on the crest next abaft that on which the stern of the ship momentarily floats. For its successful application, a ship should be placed end-on to the waves, or allowance must be made for the angle the log-line makes with the direction of the ship's course.

Observations of heights of waves.—Wave heights are, in most cases, readily measured by the following simple method: When the ship is in the trough of the sea, and for an instant upright, the observer takes up a position such that successive average wave ridges, as viewed by him from the trough, just reach the line of the horizon without obscuring it. The height of his eye above water correctly measures the wave height. In making such observations it is desirable to select a position nearly amidships, so that the in-

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fluence of pitching and 'scending may be diminished as much as possible. If it becomes necessary to take stations near the bow or stern, allowance must be made, in estimating the height of the eye above water, for deeper immersion which may be caused at the instant by pitching or 'scending. Due allowance must also be made for changes of level occasioned by rolling or heeling, as well as for the fact that when a ship end-on to the waves is in the middle of the trough the curvature of the wave hollow gives extra immersion to her ends, while the water surface amidships is somewhat below her natural water-line. To measure very high waves, the observers may have to ascend the rigging; while for waves of less height, a station on one of the decks may suffice, or some temporary expedient devised to place the observer near the water-level.

(Further data may be obtained on this subject from White's Naval Architecture.)

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CHAPTER VIII.

STRENGTH.

A ship is subjected, in service, to certain stresses. These stresses may result in strains of two kinds:

(1) Structural strains, affecting the structure as a whole.

(2) Local strains, affecting only a certain part of the whole structure.

In considering structural strains, the whole ship is generally considered as a beam or girder. From his work in mechanics, the question of beam stresses and strains when the beam is supported in various manners, is familiar to the student; also the definition of neutral axis and the derivation and application of the formula

$$\frac{p}{y} = \frac{M}{I}.$$

Where, having assumed a section,

p = stress on any fiber,

y = distance of this fiber from neutral axis,

M = bending moment to which the beam is subjected at the section,

I = moment of inertia of the section of beam about its neutral axis.

In general, considering the section of a beam, the fibers of the section farthest away from the center or neutral axis contribute most to the strength of the beam.

In designing the structural features of a ship, this principle and the principle of beam stresses are kept in mind. Thus the main deck, or upper strength deck, and its adjacent structure, and keels and inner bottom structure, for a long ship, are generally of greater strength for a given displacement than in the case of a short ship, as M is greater.

For structural strength calculations in the U. S. Service, the ship is assumed poised on a wave—

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(1) of the length of the ship $\times \frac{1}{20}$ its length in height, with crest at middle of length (Fig. 46); or,

(2) of the length of the ship $\times \frac{1}{20}$ its length in height, with the trough of wave at the middle of length (Fig. 47).

(1) results in the ends tending to droop, as the greatest support is in the middle, and is called "hogging."

(2) results in the middle tending to droop, the buoyancy being at the ends, and is called "sagging."

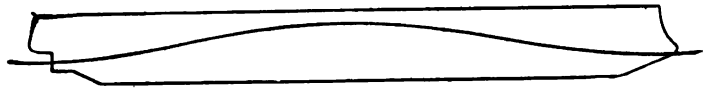

FIG. 46.

Condition (1) above is, for battleships and similar craft with heavy turrets and weights at ends, the most severe condition; (2), above, is probably worst for torpedo-craft where the principal weight is the propelling machinery amidships.

The choice of the two calculations to be made to determine the strength of the ship, should depend on type of ship, distribution of weight, and form of hull.

In well-constructed ships, these are only tendencies and no visible results occur. Should the structure not be strong enough,

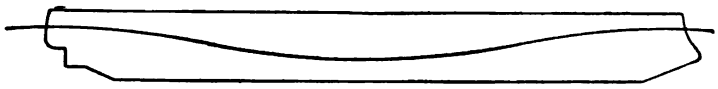

FIG. 47.

difficulty occurs. Instances are not wanting of where actual disruption has happened. Even in still water these tendencies exist in one form or another, owing to the supporting force of buoyancy differing from the corresponding weight to be supported at various points in the length of the ship. These tendencies are, however, much less than in a seaway.

The adoption of this standard calculation does not result in being able to obtain the exact stresses to which the ship is subjected, owing to the dynamical conditions present in actual service and other factors omitted from the calculations, but it permits a com-

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parison between known and tried structures, and those to be designed.

In special cases it has been necessary to employ special material of higher tensile strength than usual for the strength decks and keel structure.

The protective deck usually fitted in battleships and cruisers being located near the neutral axis, is poorly located for strength purposes, and contributes little to the structural strength of the ship as a whole, in proportion to its weight, but is necessary for the protection of machinery and magazines, and forms a secure platform from which to start upper structures, such as turret and gun foundations.

In the U. S. Service, all large vessels are framed on the longitudinal system, the keel or longitudinal center rib being continuous, as are various other fore and aft members out at the sides, called longitudinals, and the frames or transverse members forming the ribs of the ship, on which the shell plating is placed, being interrupted between these longitudinal members, or, as it is called in shipbuilding, *intercostal*. This system of framing is carried out from keel to protective deck, and fore and aft within the limits of the inner bottom, which, in the more recent ships of the U. S. Service, is carried as far forward and aft as the shape of the vessel will permit. Above the protective deck the transverse members are generally continuous. Forward and abaft the inner bottom, the transverse members are continuous and the longitudinals scored out over them, or intercostal between them. This, by consideration, will be seen to be logical, as the value of M decreases towards the ends of the ship.

For torpedo-boats and small vessels having no inner bottoms, the shell plating being necessarily thin, the transverse members are generally continuous and closely spaced to support the plating, and the longitudinals intercostal.

Warships, as compared with merchant ships in general, show the following differences:

Warships have wider frame spacing, lighter scantling, *i. e.*, thickness of material, greater extent of inner bottom, longitudinal sys-

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tem of framing instead of transverse, and more water-tight subdivisions.

All the above are possible owing to different conditions of service, maintenance, and the fact that first cost of construction is not so vitally important as the results obtained.

The U. S. regulations for care and inspection of hulls and fittings will be quoted later.

It is important that there should be no point of discontinuity in the structure, *i. e.*, the strength should not change suddenly. For this reason, where any part of a fore and aft structure is to be ended, it has to be tapered down.

Sliding or expansion joints are sometimes fitted in superstructures owing to their being of light material and far from the neutral axis so that they may not form a part of the structural strength and so be torn apart by the stresses.

Transverse stresses.—The rolling of the ship will tend to rack the structure, and, to a certain extent, the same conditions apply as in considering fore and aft stresses; but the transverse bulkheads are so numerous and the general strength in this direction so great that there need not be a matter of anxiety, except when in dry-dock, which will be treated of later.

Local strains.—All the above applies to the structure as a whole. There are certain local stresses and strains to be considered bearing on special parts of the structure:

The in and out working of the plating between frames, called *panting*. This is especially noticeable forward due to impact of ship with sea. Often additional stiffening is fitted here, or the armor being carried forward, or vertical and longitudinal ram plates and breast hooks being fitted to back up the same, accomplish the purpose desired.

Severe local strains occur under heavy weights, as turrets and barbettes, and where subjected to shock, as under gun foundations. These structures are specially designed, and are supported by beams, columns or stanchions, and bulkheads.

Engine and boiler foundations, windlass foundation, boat crane, masts, thrust blocks, and similar items require special structures.

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Bulkheads require to be designed to withstand pressures due to adjacent compartments being filled with water. In the U. S. Service, actual tests are made of all bulkheads, under pressure, in building.

The propeller struts and ram require special framing, and the armor special backing to bring out its resisting qualities.

A number of these will be treated of in some detail later.

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CHAPTER IX.

CLASSIFICATION, BUILDING, LAUNCHING, ETC.

In the U. S. Service, ships are rated as 1st rate, 2d rate, 3d rate, etc. The regulations on the subject of rating are quoted below:

Vessels of the navy shall be classed as follows (Executive Order of June 7, 1901):

(a) First rates, men-of-war of 8000 tons and above.

(b) Second rates, men-of-war only of 4000 tons and under 8000 tons, and converted and auxiliary vessels of 6000 tons and above, except colliers, refrigerating ships, distilling ships, tank steamers, repair ships, hospital ships, and other vessels constructed or equipped for special purposes.

(c) Third rates, men-of-war from 1000 to 4000 tons, converted and auxiliary vessels from 1000 to 6000 tons, refrigerating ships, supply ships, distilling ships, tank steamers, repair ships, hospital ships, and other vessels constructed or equipped for special purposes of 4000 tons and above.

(d) Fourth rates, all other rated vessels.

(e) Torpedo-boat destroyers, torpedo-boats, tugs, sailing ships, and receiving ships shall not be rated.

The general broad classifications of ships accepted throughout the world are:

(1) Armored ships, including:

a. Battleships (11,000 to 20,000 tons).

Those expected to do duty in the first line of battle, and carrying, on maximum displacement, the heaviest offensive weapons in combination with the maximum of defensive armor and reasonable speed, 16 to 19 knots.

b. Armored cruisers (9000 to 15,000 tons).

Expected to do some advance duty, but capable of taking position in the first line, carrying on displacement about equal to battleship, heavy ordnance in combination with medium defensive quality and great speed, 22 to 24 knots.

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c. Monitors (3000 to 6000 tons).
Used for harbor and coast defense.

(2) Unarmored cruising ships (3000 to 8000 tons).
Including protected cruiser type of medium displacement, with medium offensive qualities, small defensive qualities, and great speed.
Scout class, excelling in speed, but small in other qualities, and of small displacement.
In foreign services very large ships of this class have been built, but in the U. S. Service their displacement has always been kept comparatively small.

(3) Gunboats (800 to 1200 tons).
For patrol and police duty. Small.

(4) Torpedo-boat destroyers (200 to 650 tons).
Torpedo-boats (80 to 175 tons).

(5) Submarines (40 to 100 tons).

(6) Colliers, hospital ships, and auxiliaries.
Various displacements, according to service.

The Plans of a Ship and Their Reproduction in the Mold-Loft.

The explanation of the sheer draft and the relations which the sheer, half-breadth, and body plans bear to one another, has been given in Chapter II.

After the naval architect has laid down the lines of the ship, it becomes the business of the shipbuilder to accurately execute them. All the shipbuilder needs to find in the plans prepared by the naval architect is the shapes of all the various pieces of the ship; he wants to so shape each piece that it shall exactly find its place, fill its room, and fit its neighbor. The room for each piece, the space or void to be left unoccupied, the junction, face, and fitting around each piece—all *that* is to be exactly defined and measured beforehand on the floor.

The Plans.

The drawings required by the builder consist of:

1st. The sheer draft (see Plate I).

2d. The elevations, plans, sections, etc., showing the details of construction, character, and extent of the principal fittings (see Plates III, IV, and V giving sample plans).

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The sheer draft, which serves principally for the reproduction of the lines in natural size, on the mold-loft floor, consists of the following three plans:

1st. The sheer plan.

2d. The half-breadth plan.

3d. The body plan, all as shown by Plate I.

A diagonal plan is sometimes added, as it provides the best and most reliable means of *fairing* the body plan.

The other drawings comprise:

(a) Midship section, and such other transverse sections of the vessel as may be necessary to show the arrangement and size of materials used in her construction (see Plate III).

(b) The profile or longitudinal vertical section of the vessel, showing arrangement of decks, bulkheads, etc. (see Plate IV).

(c) The deck and hold plans (see Plate V).

The drawings, together with a specification describing in detail what the intended ship is to be, having been prepared, the work of preparing a half model of the ship and the laying down in the mold-loft can be commenced simultaneously.

The Model.

The plans being prepared and the scantlings determined while laying off and fairing the body, the shipbuilder usually prepares a model (or half model) in wood, of the vessel to be built, and upon that model he draws lines showing position of the frames, and then arranges the edges and butts of the shell plating. Other details, such as the intersection of transverse bulkheads and decks with side, traces of longitudinals, bilge and docking keels, position of outboard valves, struts for propellers, air ports, etc., are frequently added in the case of elaborately-designed ships like men-of-war. The model is usually made upon a scale of $\frac{1}{4}$ inch to the foot, but for very small vessels a half-inch scale is preferred. From this model, the lengths of the plates and frame angle bars are generally measured, and these materials are ordered as early as possible from the manufacturer.

Sometimes, however, the widths of the plates are measured from a drawing showing an expansion of the bottom and side of the ship.

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It is usual to order the shell plates an inch longer than the measurements obtained from the model or expansion plan, except at the more curved parts of the bow and stern, where an excess of from 2 to 4 inches is allowed. In many shipyards, the breadths of the plates are taken from the scrive-board, to be hereafter described. The lengths of the floor plates and reverse angle bars are sometimes obtained from the model or expansion plan, but generally from the body plan or mold-loft floor, or the scrive-board.

Laying Off and Fairing the Body.

Laying off is the name given to the geometrical process, by the aid of which the shipbuilder determines in full size on the mold-loft floor the forms of the various pieces of which a ship's hull is composed, so that when put together in their positions they shall collectively constitute the frame of the ship, having the exact form and dimensions intended by the designer. It may be called the geometry of shipbuilding. Recently in several shipyards and navy yards in the United States, instead of developing full size on the mold-loft floor, the development is made to 1-inch scale on a marble slab (used because it does not expand or contract), and transferred direct to scrive-board in full size.

The advantages of iron and steel over wood as a material for shipbuilding are exemplified not only in the superiority of the ships when built, but also in the comparative simplicity of all operations connected with the building of them. In no department of iron shipbuilding is this relative simplicity more apparent than in that which is carried out on the mold-loft floor. This simplicity, it should be added, is most noticeable in the case of merchant vessels, the skill and labor required in laying off a man-of-war, particularly an armor-clad, beyond that of a merchant vessel, being very considerable. This is due principally to the fact that men-of-war are built on the bracket system, with both longitudinal and transverse framing, as well as to the more complicated system of their subdivision by decks, flats, bulkheads, etc. The unarmored vessel is somewhat simpler, the problem of the longitudinal being the only addition of importance to the simpler case of the merchant vessel built on the transverse system.

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It will be sufficient for our purpose to state that, in its simplest form, "laying off" resolves itself into but little more than simply fairing the lines upon the sheer draft. This drawing is usually prepared upon a ¼-inch scale, and although every care is taken in getting the lines upon it, yet when expanded to full size, or even to ½-inch scale, discrepancies and points of unfairness are sure to be discerned. It has already been shown that the projections of each of the set of lines generally used in this process—waterlines, bow and buttock lines, diagonal lines, etc.—appear straight in one or two of the plans, and curved in others. The property which a wooden or metallic batten has of bending in a fair curve is brought to our aid in drawing the lines fairly in the plan where they appear curved. For, where the intersections of lines with each other are points, the points of intersection of two sets of lines in one plan are transferred to their relative positions in others, so that points which in one plan were in a straight line are now in a curved one. A batten is pinned or bent to pass through as many of the points as is consistent with absolute fairness, and the line is drawn. Thus, by a series of interchanges, the various lines are copied from one plan to another in full size on the mold-loft floor until at length all the plans coincide, the lines composing them are continuous curves, and having thus evidence of a continuous surface, the body is said to be *fair*.

In some yards, molds for all work are prepared directly from the plans on the mold-loft floor, but in others the body plan is transferred to the scrive-board. This consists of a number of thoroughly seasoned planks secured edge to edge by clamps, the area of the "board" being large enough to receive a copy of the body plan to full size.

As the scrive-board is kept near the bending slab, the necessary dimensions have to be taken off on battens in the mold-loft and transferred to the board.

The scrive-board should show:

1. The base line, middle line and boundary lines, waterlines, bow and buttock lines, and diagonal lines.

2. The outer edge of the frame and angle bars.

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3. The inner edges and upper boundaries of floor plates.

4. The sight and landing edges of shell plates.

5. The lines of the upper side of beams at the outer edges of the frames.

6. The middle line keelson, side stringers, etc.

7. The position of ribbands for holding the frames in their proper places (if they do not coincide with the diagonals).

8. When water-ballast tanks are fitted, or cellular framing adopted, the girders or longitudinal frames at each transverse section are shown, together with the margin or flange plates and such other lines as may be necessary in such cases.

All these lines are *razed* or scratched into the surface of the

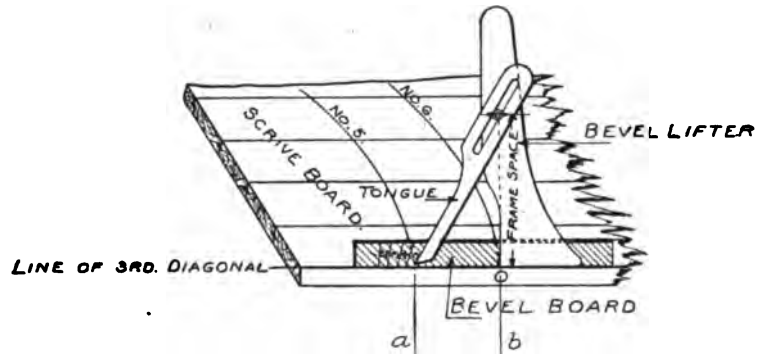

FIG. 48.

board, and some of them are distinguished by paint marks of various colors.

In order to protect the scrive-board from being burnt by the *set iron* or by the frames when checking their curvature, strips of half-round iron are fastened on the surface of the board, these being placed between the plate edges, and in directions about parallel to the latter.

Bevelings.

Beveling boards have to be prepared for the use of the workmen when setting the frames and reverse frames to the curves shown on the scrive-board.

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The bevels are taken either from the body plan in the mold-loft, or from the scrive-board, and are generally taken and applied at the intersections of the diagonals with the frames. One of the most common and correct methods used is as follows: A scale is made on a strip of wood slightly thicker than the board on which the bevels are to be marked, and is temporarily fastened to the floor in a convenient place near the body plan. From the zero point of the scale, a perpendicular is drawn, and on this set off the frame space as shown in Fig. 48. A tongue, somewhat longer than the frame space, is pivoted with one end at the extremity of the frame space, while the other end overlaps the scale. In the sketch shown, a groove in the tongue is provided for varying lengths required. Two men are required to take off the bevelings, one to take the measurements for them from the body plan, while the other adjusts the tongue to the given measurement and marks the bevel on the board. The beveling board is about 3 or 4 inches wide, with parallel edges, slightly thinner than the scale strips, so that it can be freely moved under the beveling tongue when the latter rests on the scale. The sketch shows what is theoretically the position of the instrument on the scrive-board.

Let it be assumed that the bevel is required for frame 5 at the third diagonal. A rule is applied across the intersection of the given frame and diagonal normal to the frame at that point, and the distance, *a-b*, between the frame No. 5 and the adjoining frame is taken and called out to the man at the beveling board, who then moves the tongue to the measure on the scale, and marks in the angle on the bevel board. All other bevels are taken in the same manner, the bevel board being moved up slightly at every one, so that each bevel can be clearly numbered. In taking the bevels at the rail, it will frequently occur that the head of one, or some times both, of the adjoining frames fall short of the point where the bevel has to be taken, in which case their curves have to be extended.

The frame and reverse angle bars are bent to their required form on the *bending slab* (see Fig. 49). This is composed of a number of square blocks of cast-iron with holes in them as shown. These

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blocks are fitted together, side by side, upon the ground until their united surfaces give a sufficient area for receiving the full length of any frames or other angle bar in the ship when bent.

The first operation in frame bending is the preparation of the *set iron*. This is a bar of soft iron varying from $2'' \times \frac{5}{8}''$ to $1\frac{1}{4}'' \times \frac{3}{8}''$, according to the size of the vessel.

The curves of the frame are deeply scratched upon the scrive-board, and that particular frame to be bent is carefully traced out with chalk. The set iron is then bent accurately to the shape of the

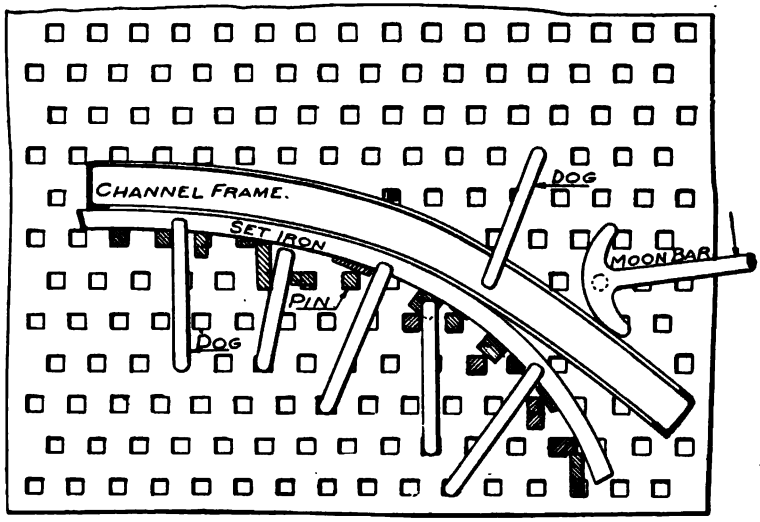

FIG. 49.—BENDING SLABS.

curve of the frame upon the scrive-board, and the positions of the beveling spots, usually the ribbands, are marked upon it. The set iron is then taken to the bending slab, and the curvature is transferred thereto with a thin slip of chalk. In some yards, instead of a set iron, a template of thin wood is made for each frame from the scrive-board and carried to the slab.

The curve drawn upon the bending slab is that of the outside of the frame, and at a parallel distance from it equal to the breadth of the transverse flange, the curvature of the inside of that flange is drawn by means of a gauge. The next step to be taken is one for

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which no rule can be laid down, as it is determined by the experience of the workmen.

It is found that in cooling, a bent angle bar not only shrinks, but also loses a portion of its curvature. A point is therefore fixed several inches beyond that given by the set iron for the extremity of the frame, to allow for contraction. At the same time a point is fixed within each extremity of the curve and the set iron is adjusted to a new curve passing through these extreme spots. In this way several inches greater curvature is obtained than is shown by the scrive-board, in order to allow for the subsequent straightening of the angle bar when cooling.

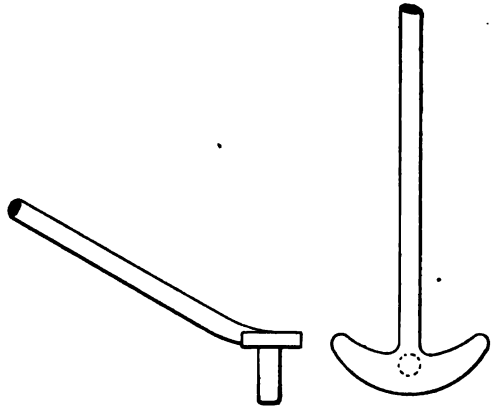

FIG. 50.—MOON BAR.

Pins are then driven in the holes of the bending slab which are nearest to the set iron, the pins being on its concave side. The intervening spaces, if any, between the pins and the set iron may be filled with circular or oval washers placed upon the pins.

All this time the frame angle bar is in a long reverberatory furnace being heated to a bright redness, almost to whiteness. When ready, it is taken from the furnace; and end of the bar is fixed by pins on both sides to the corresponding point on the slab, and then by the aid of a lever, or moon bar, such as is shown in Fig. 50, and by men pulling on a chain attached to the extremity of the bar, the latter is bent to the required curvature and secured in this position by bent pins called *dogs*, as shown in Fig. 49.

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Except at the extremities of the vessel, where the beveling is very considerable, frames are given such beveling as they require after being bent. The beveling is always *standing,* or obtuse, and for this purpose, the flanges in the forebody look aft, and in the after body, forward. The bevels having been set to the bevelings required at the different ribbands, are applied to the angle bar at the corresponding positions, and the necessary beveling is given to the bar while it is still hot, by blows from a hammer and by the aid of a suitable tool.

When the beveling is very considerable, it is generally given before bending, as the bar, being of thin substance, soon loses its heat, and after being bent becomes too cool to bevel satisfactorily. In large yards nowadays beveling is generally done before bending, by a beveling machine, and the final setting only done by hand. The final operation is to mark upon the angle iron the positions of plate edges, harpins, and other important points, nicking them with a cold chisel.

Frames for warships are generally punched for riveting after bending. Care should be taken to punch the holes *from the faying* surface (that is, the surface against which the plate lies), in order that the holes may be largest on the inside of the vessel, the hole being smallest where the punching tool enters. Rivets are generally made with a conical form under the head, so as to completely fill the rivet holes when hammered up and clinched.

Where the plate lap crosses the frame, only one rivet hole is made, in order not to weaken the frame, and this hole is always in the outer row.

The keel blocks are laid on ground previously strengthened by piling if necessary. The spacing, declivity, and sizes of the blocks are governed by the dimensions and weight of the ship to be built. The declivity is usually somewhat less than the ways subsequently laid for launching.

The height of the foremost block from the ground must be determined with great accuracy, as if there is a difference between the declivity of the blocks and launching ways, the bow comes continually nearer the ground as the ship slides into the water.

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The inner and outer flat keel plates are first planed and rivet holes punched or drilled, and after being carefully fitted, are temporarily secured to the blocks in the correct position; next the vertical keel plates and angles are fitted and their holes punched or drilled, and then the stem and sternpost, frames and longitudinals.

To keep the frames to the required form of the ship, *harpins* and *ribbands* are employed. The latter are usually made of white pine for quartering and are employed at the comparatively straight parts of the ship, while the harpins, made of oak or elm plank, trimmed to molds and bevelings, obtained with great accuracy from the mold-loft plans, are used for the more curved parts of the ship's sides. These are situated near the longitudinals, yet sufficiently clear of them not to be in the way of fitting that portion of the framing.

The ship being framed, ribbanded and faired, the beams, stringers, and longitudinals riveted in place, the plating is proceeded with In some yards, special practice obtains as to this, and the plating of the shell is begun first, the frames being set in place on top of the plating.

The strakes are lettered on the plans from the keel up, and each plate numbered in its own strake, so each plate is marked for its proper place when received. The inner or sunken strakes are always fitted first, and then the raised strakes. The edges and butts are lined off and both planed to the lines.

To give the necessary curvature to the plates, they are bent between iron rolls of the necessary length. These rolls are usually three in number. The upper roller rests in bearings, being free to revolve, but is not turned by the machinery which turns the lower two. It can be raised or lowered as circumstances require, depending on the curve desired. When being bent, the plate is lifted by a number of men, under the direction of the "plater" in charge, who hold the plate, generally with a crane, in the desired position for getting the necessary curvature and twist. The plates are bent cold unless very great curvatures is required.

The plates are carefully fitted to their places and secured to the frames by means of nuts and screw bolts. It is most important

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that the process of "bolting up" should be carefully and thoroughly done, so that the strakes may be set closely against the frames and the butt straps against the plates. When the outer strakes have been fitted and temporarily secured, the work of riveting can be begun. It is desirable that this should not be unduly delayed after the plates are screwed in place, for since the nuts and screw-bolts do not fill the rivet holes, there is always a tendency for the plates to sag.

It has only been attempted in this chapter to give a general idea of the order of the work. Details differ in different shipbuilding works, according to the practice of the yard, and change with the progress of inventions, tools, qualities of metals, etc.

Launching.

Ships, after building, require to be put in the water. This process is called *launching.*

Ships, in building, are supported on blocks forming what is called the *building slip.* These blocks, for U. S. warships, are generally 4 feet apart and their upper surface forms an incline, the declivity of which varies with the size and type of ship, varying with weight and character of ship from about $\frac{1}{2}$ inch per foot to $\frac{5}{8}$ inch per foot. While building, the keel rests on these blocks, and the ship is supported otherwise by shores and staging suitably spaced at the sides, under the bilge, etc. The building slip is generally perpendicular, or nearly so, to the shore line, in coastwise building, though on the Lakes, ships are often built broadside to the shore line.

When preparing for the launch, two timbers or combinations of timbers are laid down, one on each side of the ship and parallel to the ship's length, or nearly so, the distance apart being usually about one-third the beam of the ship. These timbers, called *ground ways,* are inclined to the horizontal in the direction of the length of the ship, at a slightly greater angle than the top of keel blocks on which the ship rests, the outer end being carried some distance out into the water; they are generally slightly inclined inwards and fitted on the outboard side with a guide timber or ribband. These ground ways are securely shored and fastened to

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FIG. 51.—VESSEL ON WAYS READY TO LAUNCH.

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the ground to prevent spreading or moving. The top surface of these ways is covered with tallow or other suitable grease whose nature is dependent on the weight of the ship and the temperature of the weather at time of launch.

On top of these ground ways are placed sliding ways which are packed up to the ship with timbers, forming a cradle in which the ship rests. These cradles are cross-connected by lashings under the keel, and the combination of sliding ways, ship, and cradle move together. Prior to launching, these sliding ways in which the ship rests are securely bolted at the shore end or sole piece to the ground ways.

When the vessel is ready to launch, wedges are placed between the sliding ways and the packing, and driven home, raising the weight of the ship off the keel blocks and bringing it on to the ways. The shores and keel blocks are then removed, allowing the ship to rest on the ways only. When ready to launch, the sole pieces are sawn off and the ship slides into the water on the grease on the ground ways. See Fig. 51, showing vessel on ways ready to launch.

It is often necessary, in confined waters, to adopt means for stopping the motion of the ship to prevent its running aground or damaging other shipping. Various means are employed to this end, such as fitting a mask over the stern to offer resistance to motion through the water, breaking stops on bights of chain, pulling wedges through resisting orifices, etc.

For detailed data of launchings, see paper by the author in Transactions of the Society of Naval Architects and Marine Engineers, 1904, and other papers in that volume and before.

Docks and Docking.

When a steel vessel becomes foul after having been for some time in the water, she requires to be docked and repainted. To do this, it is necessary that she be put into drydock, or otherwise placed where her underwater hull will be exposed. In the old days of wooden ships it was not unusual to accomplish this by heaving down or careening. Where on a shelving beach, the vessel was hove down by tackles to her mastheads, and when the tide went out, a considerable portion of her underwater body was exposed.

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The modern method takes one of three forms, *i. e.*, by exposing the bottom by means of:

(1) Graving docks.

(2) Floating docks.

(3) Marine railway.

A graving dock (see Fig. 53) is, in essentials, a basin excavated from the earth and lined with stone, concrete, wood, or other suitable water-tight material, and having a gate or mouth connected with the harbor and fitted with suitable water-tight gates or caisson. The whole has to be provided with a pumping apparatus of large capacity.

The operation of docking, in brief, is then as follows:

The dock is flooded by opening the valves provided for the purpose in the gate or caisson. When the level of water inside the dock is the same as that outside, the caisson, which is held in place by being full of water, is pumped out until it floats up out of its seat (or if gates are fitted, the gates are opened) and removed. The vessel is then brought to the mouth of the dock and the lines for handling her passed on board. There are generally 5 on each side—2 forward, 1 amidships, and 2 on quarter—and a head line for hauling the ship in. By keeping these lines tending in proper directions, the position of even the heaviest ship may be readily controlled.

It is essential that the vessel be properly centered in the dock and located exactly in a fore and aft position, and suitable sighting battens and measuring arrangements are provided on the dock coping for this purpose.

In the U. S. Service, the regulations provide that docking shall be done by the Naval Constructor of a yard, and he is responsible for the vessel from the time her bow reaches the sill, going in, until it crosses it, going out.

Vessels generally go into dock bow first. While in dock it is essential that no radical change in the distribution and amount of weight on board be made, such as putting on board or removing considerable amounts of coal or water, or shifting ammunition or coal from one space to another, and no change should be made

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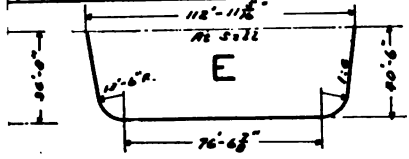
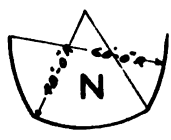
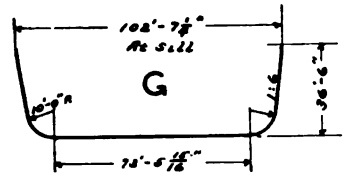
Greatest depth from Coping to Floor in Body of Dock	Mean Rise and Fall of Tide.	Date of Commencement.	Date of Completion.	Cost to date of Completion.
39'- 7½"	7'-7"	1899		Under Construction
32'-0"	10'-0"	1827	1833	972,717.29
39'- 2"	10'-0"	1899		Under Construction
32'-0"	4'-8"	1841	1851	2,003,998.05
32'-10"	4'-8"	1887	1895	1,171,955.00
35'-6"	4'-8"	1893	1897	559,707.08
39'-8"	4'-8"			
33'-7'	6'-2½"	1889	1891	598,700.00
41'-6" At Centre 41'-3" At edge	6'-2½"	1899		Under Construction
32'-0"	2'-9"	1827	1834	943,676.00
32'-10"	2'-9"	1887	1889	504,980.76
41'-0"	2'-9"	1903		Under Construction
42'-6"	5'-1½"	1902		Under Construction
36'-5½"	5'-0"	1872	1891	2,772,332.08
	6'-0"	1899		Under Construction
39'-3"	8'-1½"	1892	1896	632,636.33



*Note:- These dates added January 9, 1905.





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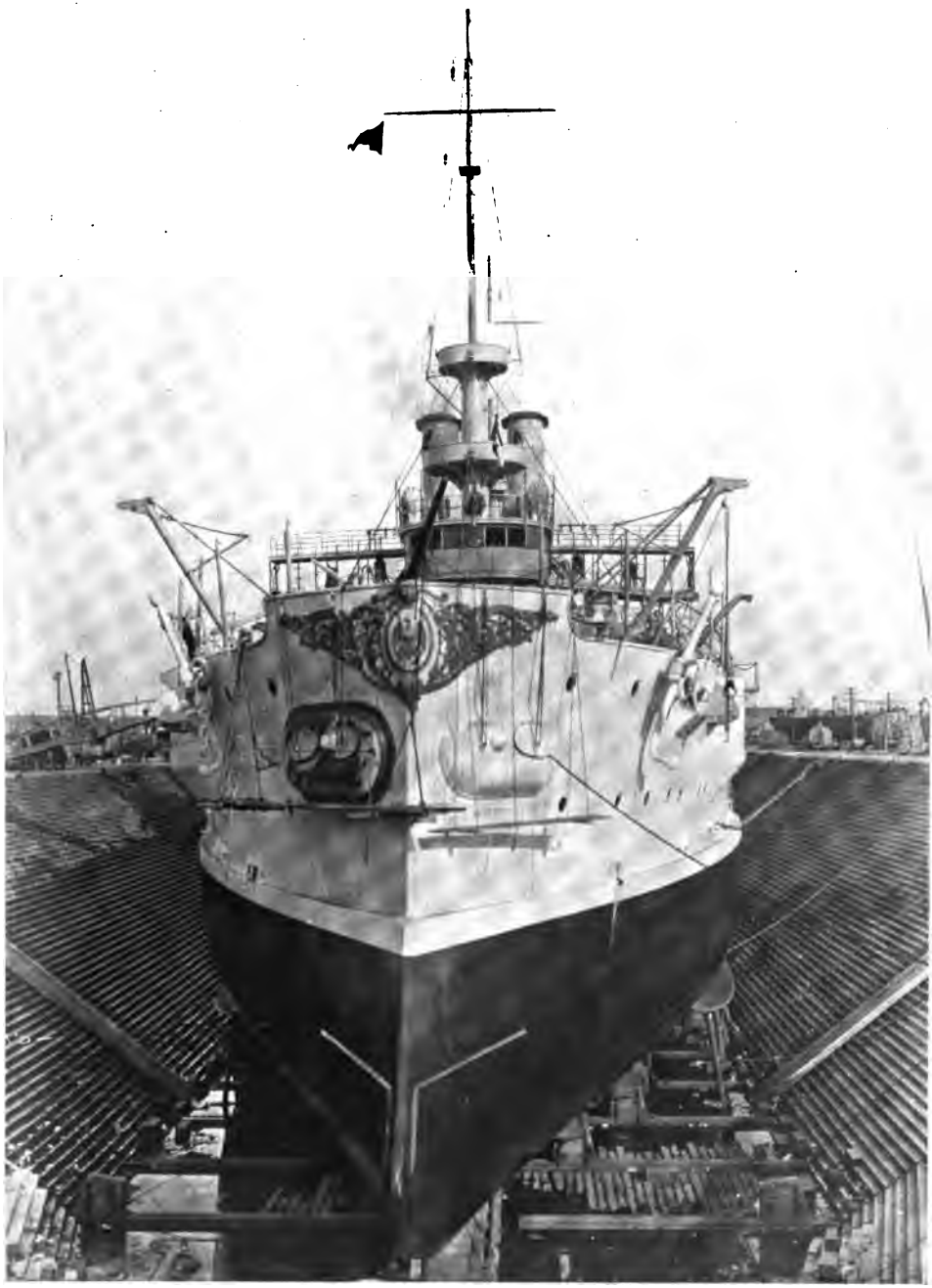

FIG. 53.

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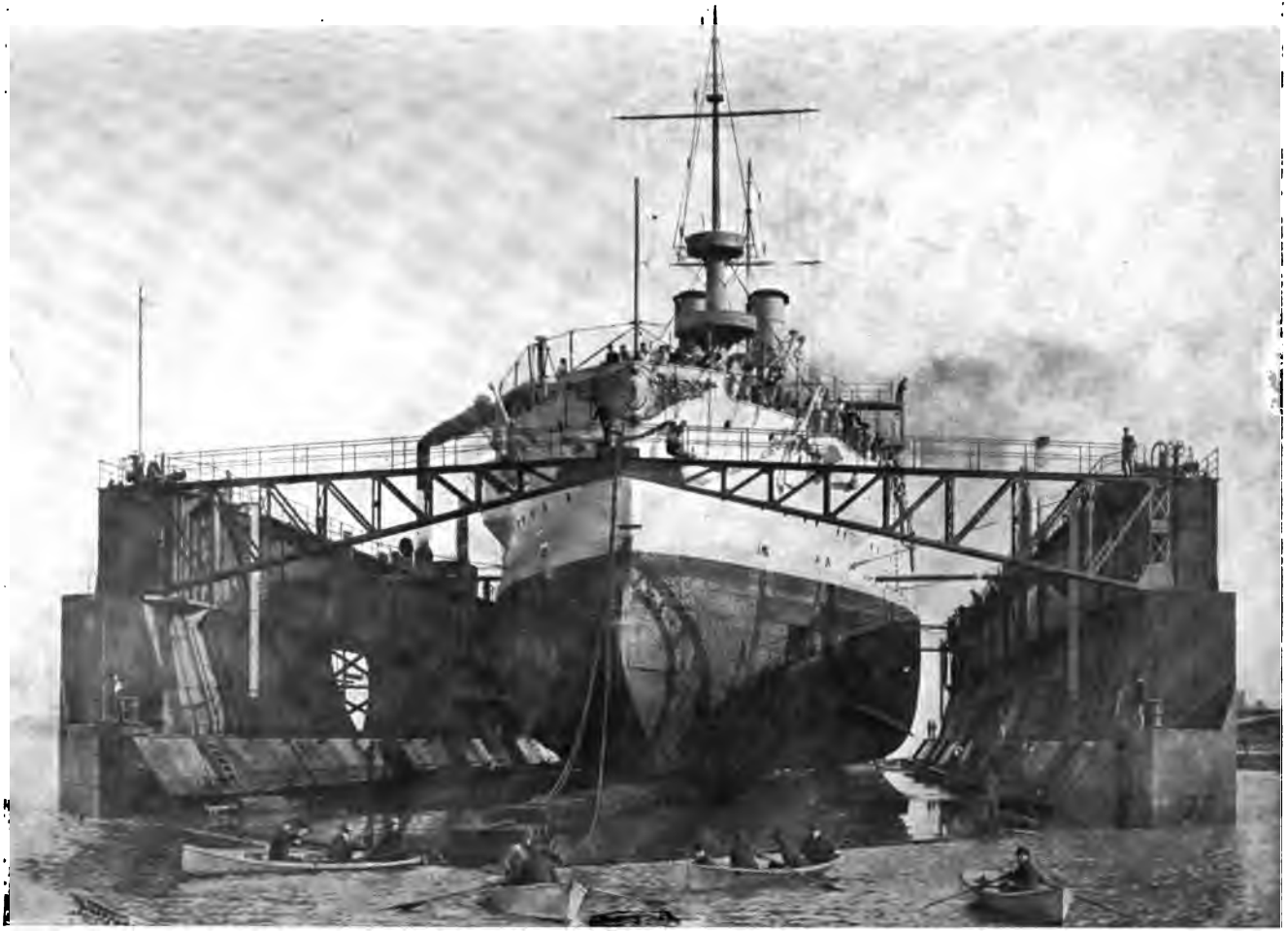

FIG. 54.

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Date of Completion.	Cost to date of Completion.	Remarks.
1851	$ 800,805.90	*121'-0" At Pump Houses. 107'-0" At Gate
	• 102,470.00	
* 1902	* 809,712.82	Total length over fenders 527'-10
1897	• 195,000.00	
* 1906	* 1,139,049.59	

• Purchase price.
* Added December 23. '05.

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without the knowledge of the officer responsible for the vessel while in dock.

When the ship is properly located, the caisson is floated back into place, sunk into its seat, and the pumps started; and as the water inside the dock goes down, the vessel settles onto blocks fitted in the bottom of the dock to receive the center-line keel and docking keel's, and is supported by these, together with certain sliding blocks under the bilges, and shores fitted at sides and under bilges.

The table in Fig. 52 shows the number, kind, and size of U. S. Government drydocks, with their location:

Floating docks are radically different. They are huge box-structures of steel or wood, with high sides and open ends, as shown in Fig. 54. They are fitted with flooding and pumping arrangements of large capacity. When it is desired to dock a vessel, the floating dock is sunk so that nothing but the sides project above the water. The ship is then towed in between the walls, and the dock is pumped out and rises, so that it lifts the ship, which rests on keel blocks arranged in the same manner as for graving docks.

Great skill is required in handling a dock of this character, to prevent straining the dock and the ship to be docked. Such a dock is cheaper than a graving dock, but obviously requires more care, being as it is, a steel structure. It therefore requires to be docked itself, and is usually made in three sections so that the individual sections may be docked separately by the other two. A list of such docks in U. S. Service is shown in Fig. 55.

Marine railways.—This method of exposing the underwater portion of a vessel is applicable only to the smallest size of warships. It consists essentially of an inclined railway projecting out into the water, and a suitable endless-chain hoisting arrangement, such that the vessel can be hauled up out of the water on this way, in about a reverse process to that of launching.

NOTE.—For additional data as to docks, see Notes on Docks and Dock Construction, by C. Colson.

For balance of chapter, see U. S. Naval Regulations, Transactions Society N. A. & M. E.; Watson's Manual of Laying off.

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CHAPTER X.

MATERIALS, TESTS, AND FASTENINGS.

In general, material for the ship's structure, in the U. S. Service, is mild steel, whose manufacture and general properties have been treated in Barton's Mechanical Processes. It is required to be made by the open-hearth process, and is inspected by representatives of the Government on the ground during manufacture, and tested after finishing but before shipment. The details of the requirements for this material may be found in "Specifications for Inspection of Hull Material for Vessels of the United States Navy." In brief, these requirements are as follows:

Material may be rejected at the building yards or at navy yards, for surface or other defects, either existing on arrival or developed in working, although previously passed at mill.

Test pieces for tensile tests must be uniform in cross-section for a length not less than 8 inches. Sectional area of such test pieces as in the finished size do not come within the capacity of the testing machine, shall be not less than 0.5 of a square inch in area and shall have the width as nearly as possible three times the thickness.

Each tensile piece shall be subjected to a direct tensile strain in a machine of approved character, running at a slow speed until the elastic limit is reached, and then at a medium speed until the piece is broken. The tensile strength herein specified means the ultimate strength per square inch of original cross-section, and the elongation referred to is that obtained after fracture.

Specimens for cold and quench bends for plates and shapes shall be rectangular in shape, and, when practicable, 12 inches long and of a width of from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches.

The material is classified in four standard grades according to its characteristics and the purposes for which it is intended. These grades are known as (1) standard soft; (2) standard medium steel; (3) standard hard steel; (4) common steel.

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Standard Soft or Flange, Medium, and Hard Steel.

Kind of material.—Plates and shapes shall be of steel or nickel steel, made by the open-hearth process, and must not show more than six one-hundredths of 1 per cent of phosphorus; and not more than four one-hundredths of 1 per cent of sulphur for acid steel; and not more than four one-hundredths of 1 per cent of phosphorus, nor more than four one-hundredths of 1 per cent of sulphur for basic steel. The material shall be of the best composition in all other respects.

At the option of the manufacturer the material may be annealed.

The following are the requirements of each of the above grades of steel except common, which being used for liners only requires no special inspection:

Grade.	Tensile strength.	Elongation.	Cold bend.	Quench bend.
Soft or flanged steel.	50,000 pounds	30 per cent.	180° flat.....	180° flat.
Medium steel	60,000 pounds	25 per cent.	For material below ¾ inch in thickness: 180° flat for longitudinal; 180° to diameter of 1 thickness for transverse. For material ¾ inch in thickness and above, the bends will be 180° to a diameter of 1 thickness for longitudinal, and 2 thicknesses for transverse specimens.	For material below ¾ inch in thickness: 180° to diameter of 1½ thicknesses for longitudinal; 180° to diameter of 2½ thicknesses for transverse. For material ¾ inch in thickness and above, the bends will be 180° to a diameter of 1½ thicknesses for longitudinal, and 2½ thicknesses for transverse specimens.
Hard steel....	75,000 pounds	18 per cent.	180° to a diameter of 1½ thicknesses for longitudinal; 180° to a diameter of 3 thicknesses for transverse.	No quench bend.

Inspection for surface and other defects.—Plates and shapes must be free from slag, foreign substances, brittleness, hard spots, laminations, sand or scale marks, scabs, snakes, pits, and defects generally. Light plates, not more than 10 lbs. weight per square foot, must be reasonably free from waves or buckling. Shapes

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must also be free from defective sections, shaded backs, grooved fillets, imperfect edges, crookedness, unfairness, etc.

Weighing.—Plates of 12½ lbs. per square foot and less, and strips and bars of 6 lbs. per linear foot and less, may be accepted if the weights vary between 3 per cent above and 5 per cent below the specified weights. All other plates and shapes may be accepted if the weights vary between the specified weights and 5 per cent below them.

In working mild steel, as few heatings should be made as possible, and when heated, the material should never be worked below a red heat.

As punching changes the internal character of material to some extent, important butt straps should be drilled, or after punching, be annealed.

In the U. S. Service it is customary to pickle plates and shapes forming the structure below water-line before working up into the ship. This removes such of the rust or mill scale as still remains, which, if not removed, might later peel off under the paint and flake the paint off, allowing corrosion. Mill scale is electro-negative to the steel, and corrosion would occur if these two were immersed together in sea water.

The material is immersed for several hours in a tank containing one part hydrochloric acid and 19 parts water; then removed and dipped in lime water; then washed with hose and brushed with wire or coir brushes during the washing.

It is customary, in U. S. practice, to let the balance of the steel stand in the air, unpainted, for a certain time, which results in a rust coating forming and loosening the mill scale. The material then requires to be carefully brushed and cleaned before painting.

Rivet Material.

As the efficiency of joints, and, consequently, of the whole structure, depends upon the rivet strength, great care must be exercised to get this material of the best. The following are the requirements:

Kind of material.—Steel for hull rivets shall be made by the open-hearth process, and not show more than five one-hundredths of one per cent of phosphorus, nor more than four one-hundredths

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of one per cent of sulphur, and be of the best composition in other respects.

Tensile test.—The rods rolled from any heat shall be tested by sizes, and one tensile test specimen shall be taken for each ton or fraction thereof. Not less than two tensile tests shall be taken from any one size from any heat.

Bending tests.—From each heat of rivet rods as finished at the rolls, four cold-bending tests shall be taken, which shall be bent over flat on themselves without showing any cracks or flaws on the outer round.

Rods from which rivets are to be made will be tested in the diameter of the finished rods. Rods of half inch or less shall show a tensile strength of not less than 58,000 pounds per square inch, and an elongation of not less than 28 per cent. Rods over one-half inch in diameter shall show a tensile strength of not less than 58,000 lbs. per square inch and an elongation of not less than 29 per cent.

From each lot of rivets of each size kegged and ready for shipment, there shall be taken at random six rivets, to be tested as follows:

(a) Three rivets to be flattened out *cold* under the hammer to a thickness of one-half the diameter of the part flattened, without showing cracks or flaws. Rivets of over an inch in diameter shall be flattened to three-fourths of the orignal diameter.

(b) Three rivets to be flattened out *hot* under the hammer to a thickness of at least one-third of the original diameter of the part flattened, the heat to be the ordinary driving heat.

Inspection for surface and other defects.—Rivets must be true to form, concentric, and free from scale, fins, seams, and all other injurious or unsightly defects. Tap rivets will be milled under the head if necessary to obtain accuracy.

Certain important parts of a warship's structure are now usually made of steel castings, such as the stem and sternpost, rudder frame, shaft struts, bitts, cleats, etc.

The following tests as prescribed for steel castings are quoted:

Steel for castings shall be made by the open-hearth or crucible process, and shall contain not more than six one-hundredths of one per cent of phosphorus, and shall be of the best composition in all other respects, and uniform in character throughout each casting.

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Test specimens.—Sound test pieces shall be taken in sufficient number to thoroughly exhibit the character of the metal in the entire piece from each of the following castings, viz.: Stem, stern frame, rudder frame, shaft struts or brackets, and all large castings weighing over 200 pounds. All other castings may be tested by lots, as follows: A lot shall consist of all castings from the heat annealed in the same furnace charge. From each lot, two tensile and one bending specimen shall be taken, and the lot shall be passed or rejected on the results shown by these specimens. The specimens may, at the discretion of the inspector, be cut either from coupons to be molded and cast on to some portion of the casting, or from sinking heads, in cases where such heads of sufficient size are employed. Coupons must be so fixed as not to interfere with the successful making of the casting, but at the same time to show the quality of the material. In the case of castings tested by lots, the test pieces may be taken from the body of a casting from the lot, if so desired by the manufacturer. If there are any unsound test specimens coming from a casting, the inspector shall examine carefully to detect porosity or other unsoundness in the casting itself.

Tensile tests.—The tensile strength of steel castings for hawse pipes, turret tracks, and all important parts subject to crushing strains or surface wear only, shall be not less than 70,000 nor more than 80,000 lbs. per square inch, with an elongation of at least 8 per cent in 8 inches, or 15 per cent in 2 inches.

Bending test.—When the elongation is taken over a length of 8 inches in the tensile test, one or more test specimens from each object named above, or each object greater in weight than 200 pounds, or one or more test specimens from each lot of smaller objects, 1 inch square, shall be bent cold through an angle of 90° over an inside radius of 1½ inches without showing cracks or flaws.

When the elongation is taken over a length of 2 inches, the bending test specimen, 1 inch wide by ½ inch thick, shall be bent cold through an angle of 120° over an inside radius of 1 inch without showing cracks or flaws.

Drop and hammer test.—Castings for stems, sternposts, shaft brackets, turret roller tracks, bedplates, foundations, and such other important castings as may be specified, shall be subjected to

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drop and hammer tests as follows: Castings weighing more than 1500 pounds shall be raised to a height of at least 10 feet and be allowed to fall freely from that height upon a concrete or other surface of a hardness equal to that of a good macadamized road. Castings weighing less than 1500 and more than 1000 pounds shall be allowed to fall freely from a height not less than 12 feet, and

FIG. 56.—CORRUGATED METAL.

castings weighing less than 1000 pounds from a height not less than 15 feet upon a concrete or other surface of a hardness equal to that of a good macadamized road. After the above test, the castings specified are to be suspended in chains and hammered all over with a heavy sledge hammer. No cracks, flaws, defects, or weakness must appear after such treatment.

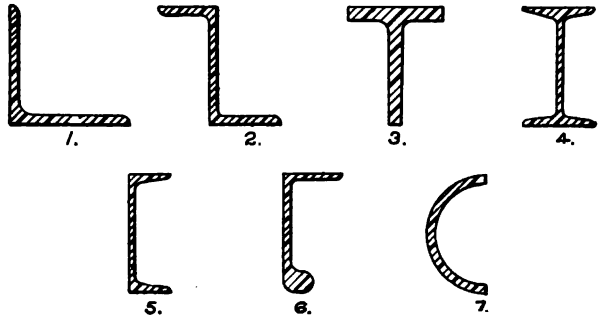

FIG. 57.

(1) Angle. (2) Z-bar. (3) Tee-bar. (4) I-bar.
(5) Channel. (6) Angle-bulb. (7) Half-round (hollow or solid).

Inspection for surface and other defects.—All castings must be sound, free from brittleness, injurious roughness, sponginess, pitting, porosity, shrinkage, and other cracks, cavities, foreign substances, and all other defects affecting their value. Particular search must be made at the points where the heads or risers join in the castings, as unsoundness at this point is thought likely to extend into the castings.

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Certain important parts of sheathed ships, such as stem, sternpost, shaft struts, etc., and many of the detail parts of every ship's fittings, are made of bronze or composition, to prevent corrosion. A specification similar to the steel specifications, called "Specifications for Inspection of Hull Material, Alloys of Copper, Tin, and Zinc," is issued covering the composition to be used for various purposes.

Shipbuilding shapes ordinarily used in the U. S. Service, for hull structures, are:

Plates, gauged by pounds, a plate 1 foot square and 1 inch thick being 40 lbs. A ¼-inch plate is spoken of as a 10-lb. plate.

Sheets, whose thickness is measured by one of the gauges (in the U. S. Service by U. S. standard gauge), and spoken of as No. 12, No. 16, etc. These may be black, or galvanized, plain or corrugated sheets, *i. e.*, sheets bent so that a cross-section looks as in Fig. 56, and certain *shapes:* (see Fig. 57), and various special shapes built up of combinations of the above shapes as Fig. 58.

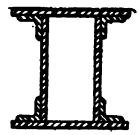

FIG. 58.—BOX GIRDER. (Box Girder made of plates and angles.)

Shapes are designated by the dimensions of flanges and the weight per foot as a 5″ × 3½″ × 12 lb. angle.

Referring to Fig. 57:

(1) is used for connections of plates to plates when meeting at an angle, as of bulkheads to decks, etc.

(2) is used for frames outside of inner bottom, bulkhead stiffeners, etc.

(3) is used for deck seam straps, mast seam straps.

(4) is used for bulkhead stiffeners and special fittings.

(5) is used for deck beams and stiffeners.

(6) formerly used exclusively for deck beams; lately not used at all.

(7) is used for moldings and finishings.

The proper combination of these shapes permits the maximum of rigidity and strength to be obtained for the minimum of weight.

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Rivets.

In the U. S. Service the forms of rivets used are, before driving, as in Fig. 59.

(1) Pan head—with straight shank or conical neck.

(2) Countersink head—made in various angles for various sizes of rivets.

(3) Tap rivet, or tap bolt.

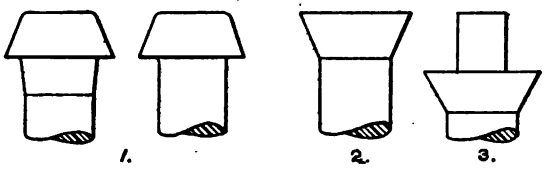

FIG. 59.

These fit into holes in the plates or shapes, as in Fig. 60.

(1) Drilled; when drilled, generally made 1/16 larger than rated size of rivet when cold.

(2) Punched from side *AB;* gives a hole expanding downward. All holes in structural work in U. S. Service are punched when material is 1 inch thick, or less; above that, drilled. When punched and fastened together ready to rivet, holes are faired by reaming,

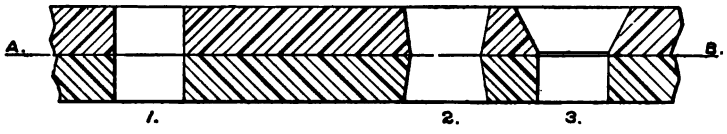

FIG. 60.

i. e., putting in a revolving fluted reamer, usually nowadays operated by an air drill.

(3) Countersunk, *i. e.,* drilled out in a conical form by a pointed drill before riveting, and of such angle of cone as to take the rivet head suited for the proper thickness of plate.

Points.

The rivets, when more than $\frac{3}{8}$", are always heated in a forge and driven hot. The end "upset" by the riveting hammer is called the

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point. The types of points used in the U. S. Service are as in Fig. 61.

(1) *Snap* or *button,* used for work requiring finished appearance.

(2) *Flush,* generally used, and for watertight work when smooth work is required.

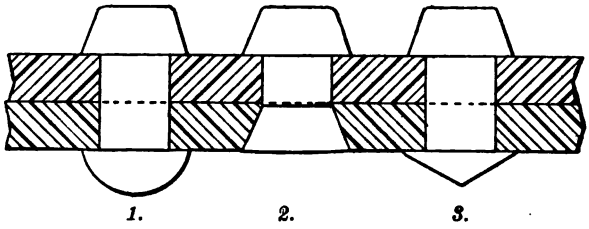

FIG. 61.

(3) *Smashed,* used where (1) and (2) are not desirable or necessary.

Tap rivets, having a thread on the shank, require the hole to be threaded or tapped, and are not used for through connections; they have a square projection on the head for screwing up and this is afterward cut off. (See Fig. 62.)

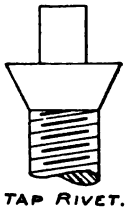

FIG. 62.

Special types of through bolts or tap bolts and machine screws are used where absolutely necessary, such as in Fig. 63.

Plates requiring to be fastened together are either lapped or butted.

The general forms of such connections are as in the sketches given below, but the spacing and number of rows of rivets employed, *i. e.,*

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whether single, double, treble, or quadruple, depends on the thickness of the plates and the service to which the joint will be put.

These points are determined by various rules given in the "Standard Instructions for Riveting U. S. Naval Vessels," or calculated for each particular case to obtain the maximum strength.

Edges of plates are usually lapped, but when butted are fitted

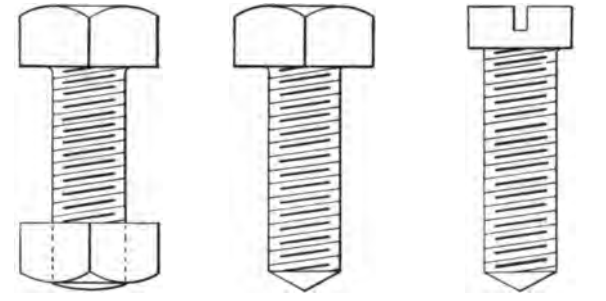

FIG. 63.

with a *seam strap*. When end-on connections of plates are to be flush, a *butt strap* is fitted. Double butt straps are sometimes fitted, in which case each strap is thinner than where a single strap is fitted.

End connections of angle bars are made by what is called a *bosom piece*. (Fig. 64.)

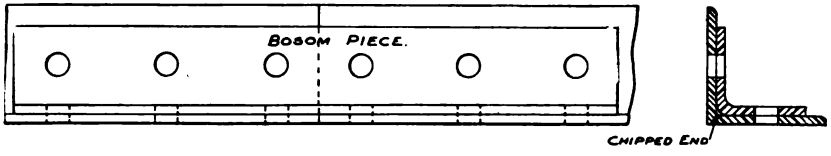

FIG. 64.

The size of rivets, the spacing of rivets in the rows, and of the rows from the edge and from each other, is an important matter, and all are treated in detail in the instructions mentioned above.

In general, centers of holes should be not less than $1\frac{5}{8}$ times the diameter of rivet from edge, and for double or treble riveting, centers of holes in adjacent rows not less than $2\frac{1}{2}$ diameters apart.

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The spacing of rivets in the same row depends on the service: If watertight, the spacing varies from 3½ to 5; oiltight, 3½ to 4; non-watertight, 6 to 8.

Types of connections between plates are shown in Figs. 65 to 73.

Calking.

After fastening together two plates, if the joint requires to be watertight it must be calked. If it is a butt joint, it requires butt

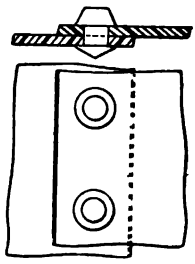

FIG. 65.—SINGLE RIVETED LAP.

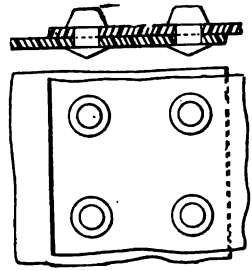

FIG. 66.—DOUBLE RIVETED LAP.

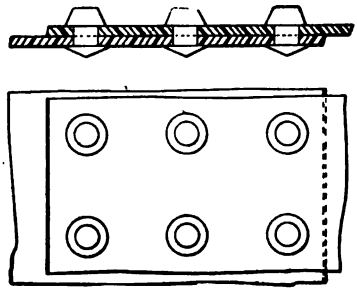

FIG. 67.—TREBLE RIVETED LAP.

calking, and the edges of plates must be planed. The edge of each plate near the joint is split and the two edges forced together with a hollow tool. If it is a lap joint, it requires edge calking. The edge of plate is either planed or chipped and then split and forced down against the other plate.

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Butt calking is not so efficient as lap calking or edge calking, being more liable to be pulled apart. (See Figs. 74 and 75.)

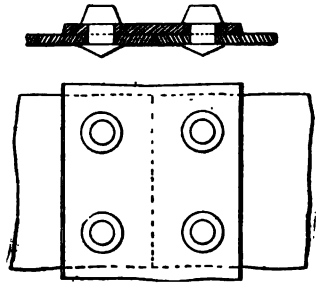

FIG. 68.—SINGLE RIVETED SINGLE STRAP.

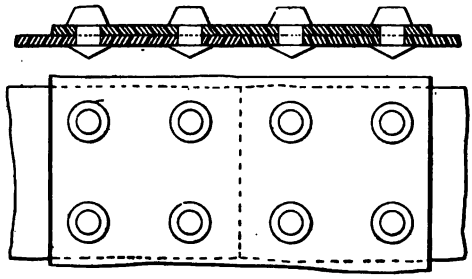

FIG. 69.—DOUBLE RIVETED SINGLE STRAP.

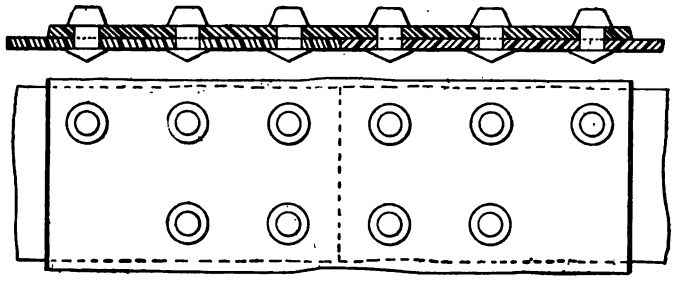

FIG. 70.—TREBLE RIVETED SINGLE STRAP.

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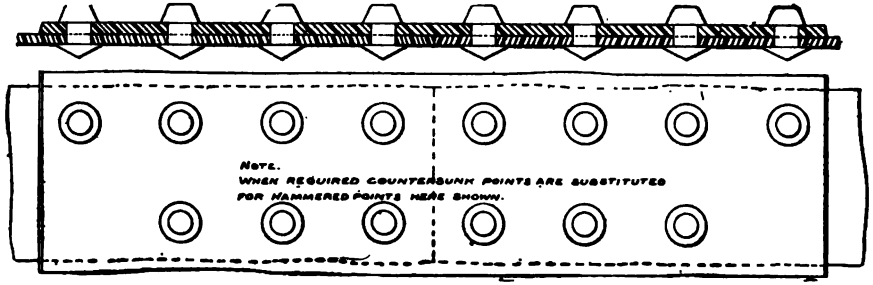

FIG. 71.—QUADRUPLE RIVETED SINGLE STRAP.

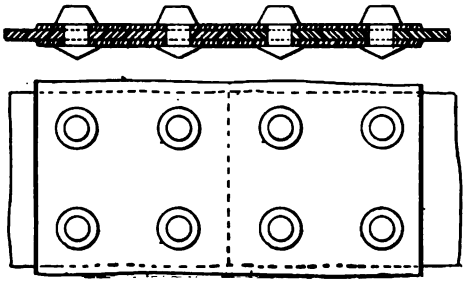

FIG. 72.—DOUBLE RIVETED DOUBLE STRAP.

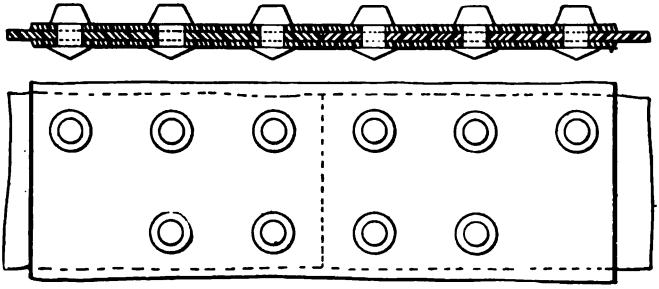

FIG. 73.—TREBLE RIVETED DOUBLE STRAP.

FIG. 74.—LAP CALKING.

FIG. 75.—BUTT CALKING.

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NOTE.—References have been given in the text of this Chapter to the pamphlets issued by the Bureau of Construction and Repair, Navy Department, on tests and inspections of steel material, instructions for riveting naval vessels, etc. Further information may be found in Reuleaux Constructor, and in article by Naval Constructor J. H. Linnard, U. S. N., in the Transactions of the Society of Naval Architects and Marine Engineers, 1896.

Detailed Calculation of Weights and Centers of Gravity.

It is necessary in designing to estimate the weight and the positions of centers of gravity of each part of the ship's structure, fittings located thereon, and machinery and appurtenances therein, in order that the predetermined draft, trim, and stability conditions may prevail in the finished design.

A preliminary estimate of the above is made from preliminary plans. The weights per foot, of the ship's structure alone, are calculated and plotted as ordinates at their proper locations on a base line representing the length of the ship. These spots determine a curve the area under which, increased by the weight of transverse bulkheads and irregularities of construction, is very approximately the weight of the ship's structure alone. Fittings and various appurtenances are estimated by percentage allowances based on existing ships of similar design, and the machinery weight figured from weights of previous machinery, knowing the H. P. required to obtain the desired speed estimated from model experiment. On these preliminary estimates, the final design and specifications are based, but a more detailed and complete estimate is made before the actual work is undertaken, as outlined below.

The ordinary rules of mensuration employed in ship calculations were discussed in Chapter III. The details of construction of the ship's structure and scantlings of its various component parts are in the specifications. All plates are specified in weight per square foot, and the various shapes of beams, frames, stiffeners, etc., in weight per lineal foot, the standard sizes being shown in the hand-book of any steel mill, such as Carnegie's. In the case of a bulkhead, a deck, the outside plating, or inner-bottom plating, the first step is to find the area of plating and length of angle bars. To determine

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the former, the plates are laid off on a plane surface. If the plating is warped, it is developed on a plane surface so as to give, as nearly as possible, its true area. To this net area is added the area of seam-straps, butt-straps, laps, and liners. The weight of the plating is the weight of this total area, with a deduction for rivet holes. This per cent deduction varies somewhat with the size and spacing of the rivets, but is commonly taken as 1½ per cent.

The use of curves is often of great assistance in determining the weight of certain parts of the structure. Take, for instance, the transverse framing of a ship. For a considerable portion of the length of the ship, this framing will be of the same character. Let the length over which this type of framing obtains be represented by a base line on which the location of each frame is spotted. The length of a convenient number of frames is measured from the body plan and their calculated weights set up to a certain scale as ordinates at their proper locations on the base line, and through the spots thus obtained a fair curve is drawn. This curve is the locus of the weights of all frames within the extent of the base line. The individual weights of deck beams may be determined in the same manner. A close approximation to the total length of deck beams or stiffeners for a given area of deck or bulkhead may be obtained by dividing the area by the spacing of the beams or stiffeners. In obtaining all the first approximate areas and centers of gravity, the planimeter or integrator is of great value, but in the final calculation, one of the rules in Chapter III is employed.

Allowances for the weights of such indeterminate portions of the structure as rivets (driven), paint, putty, and cement, are based on the returned weights of similar ships, or in an entirely new class of vessel, must be calculated in great detail.

The fittings, machinery, and appurtenances are based on official returned weights modified by the latest official data from the various Bureaus having cognizance thereof.

By the use of these various methods, the weight of each portion of the complete ship may be calculated. It is quite natural, however, from the complexity of the modern vessel of war, that such calculations must be made according to a fixed standard or grouping or classification to keep the work within reasonable limits of cost

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and also for purposes of comparison. Several methods of grouping the weights for such purposes suggest themselves. Without discussing such natural divisions, briefly, the method adopted in the Bureau of Construction and Repair is to group each deck separately. The outside plating, inner-bottom plating, bulkheads (transverse and longitudinal), machinery supports and fittings, are grouped separately. The propelling machinery, armor, ordnance, equipment, and outfits are likewise separately grouped. The Bureau of Construction and Repair uses fifty-five groups and keeps a carefully recorded return of official weights, which is compared with the estimates, reduced to percentages, and otherwise used for new designs.

Printed forms for detailed weight calculations are provided, upon which are entered a description of the object, with its unit weight and number of units, together with leverages for each item, about two axes (the moulded base line of the ship being one, and the frame most nearly coincident with the mid-length the other). Such weight sheets are compiled according to groups and finally summarized, giving the total of each group, together with the derived position of its center of gravity. All of the groups being recapitulated, the gross weight of the ship with everything on board ready for sea, is obtained, and at the same time the longitudinal position of the center of gravity of the ship and its height above the moulded base line. From the displacement sheet (previously described), the functions of form to the load waterline are obtained, and knowing the position of the center of gravity, center of buoyancy, moment to alter trim of ship one inch, and the metacenter, the metacentric height and trim of the ship is calculated.

The records of calculated weights are preserved in the Bureau, and upon completion of the vessel, careful checks are made between the calculated and actual weights as well as between the designed trim and metacentric heights and the results of the final inclining experiment.

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CHAPTER XI.

KEELS AND FRAMING.

A navy is necessarily made up of different types of vessels to perform different functions. No attempt will be made in this book to exhaustively describe the construction of each type of vessel in the Navy. Certain main types will be treated of, and it will be seen that the intended service has great bearing on the construction of the vessel.

First-Class Battleships.

These ships are heavily armored and armed and have a speed moderate as compared with that of armored and other fast cruisers. One distinctive feature, which is shared only by the latest armored cruisers, is the provision of an inner skin up to the protective deck.

Sections of the several generally distinctive types of battleships in the U. S. Service are shown in Figs. 76, 77, and 78 following:

The inner bottom is generally 39 inches above the outer bottom at middle line, the depth decreasing slightly towards the bilge. In our earlier ships (see Fig. 77) it was continued up to the protective deck from about the watertight longitudinal No. 5 in the form of a vertical bulkhead or wing bulkhead. In our later ships it is continued to the protective deck as an inner bottom. There is, in addition, the inner coal-bunker bulkhead, so that at side and bilges there are at least three skins to pierce before a vital part of the ship is reached. At the bottom there are only two skins.

A double-bottom arrangement of some form is employed in the U. S. Service for all vessels above the gunboat type in size. The inner bottom provides an inner skin in case of damage, and the double-bottom space is always subdivided by watertight floors and longitudinals into a number of watertight compartments, and so localizes any damage. A part of the inner bottom is generally arranged as a tank for *reserve feed water* for boilers.

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RESERVE CORL

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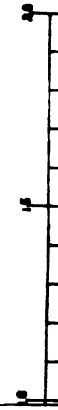

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In our earlier battleships, the protective deck was flat and a thick belt of armor fitted: For the *Indiana,* 18 inches; for the *Alabama,* 9½ inches bottom, 16½ inches top. In the more recent ships, the improvement in armor has permitted its decrease in thickness and increase in area, and the protective deck has been made level at middle line, but sloped to lower edge of armor at the sides.

Longitudinal framing.—The main framing of a battleship is on the longitudinal system. This framing, below protective deck, consists of a continuous vertical keel and a certain number of continuous longitudinal girders on each side, generally seven, including the armor shelf on ships of the *Indiana, Kearsarge, Kentucky, Alabama,* and *Maine* types, and seven, exclusive of armor shelf, on ships of the *Connecticut* type and later.

In our earlier battleships, the vertical keel was generally watertight, but more recently has been made non-watertight, the first watertight longitudinal generally being No. 4, though sometimes higher up. The vertical keel is 25 lbs., with two angles at bottom 4″ × 3½″ and two at top 3½″ × 3″. These, with the middle plate of the inner bottom and the inner and outer plates of flat keel, form the backbone of the ship.

The plates of the vertical keel are connected by double butt-straps of 15 lb. plate, treble riveted, with alternate rivets in outer row omitted, the straps extending between the toes of upper and lower angles. Adjacent lengths of angles are connected by bosom pieces.

The longitudinals are 22½-lb. plate over about two-thirds the length of the ship, reduced at forward end to 15-lb. and at after end to 20-lb. They have a single angle at bottom 3½″ × 3½″, intercostal between frames, and a single continuous angle at top 3½″ × 3″, the 3½″ flange being necessary for the ⅞″ rivets to outer bottom and longitudinal, and the 3″ flange being sufficient for the ¾″ rivets to inner bottom. These longitudinals are worked as near as possible square to the outer bottom.

The arrangement of riveting depends on whether the longitudinal is watertight or non-watertight. Non-watertight longitudinals

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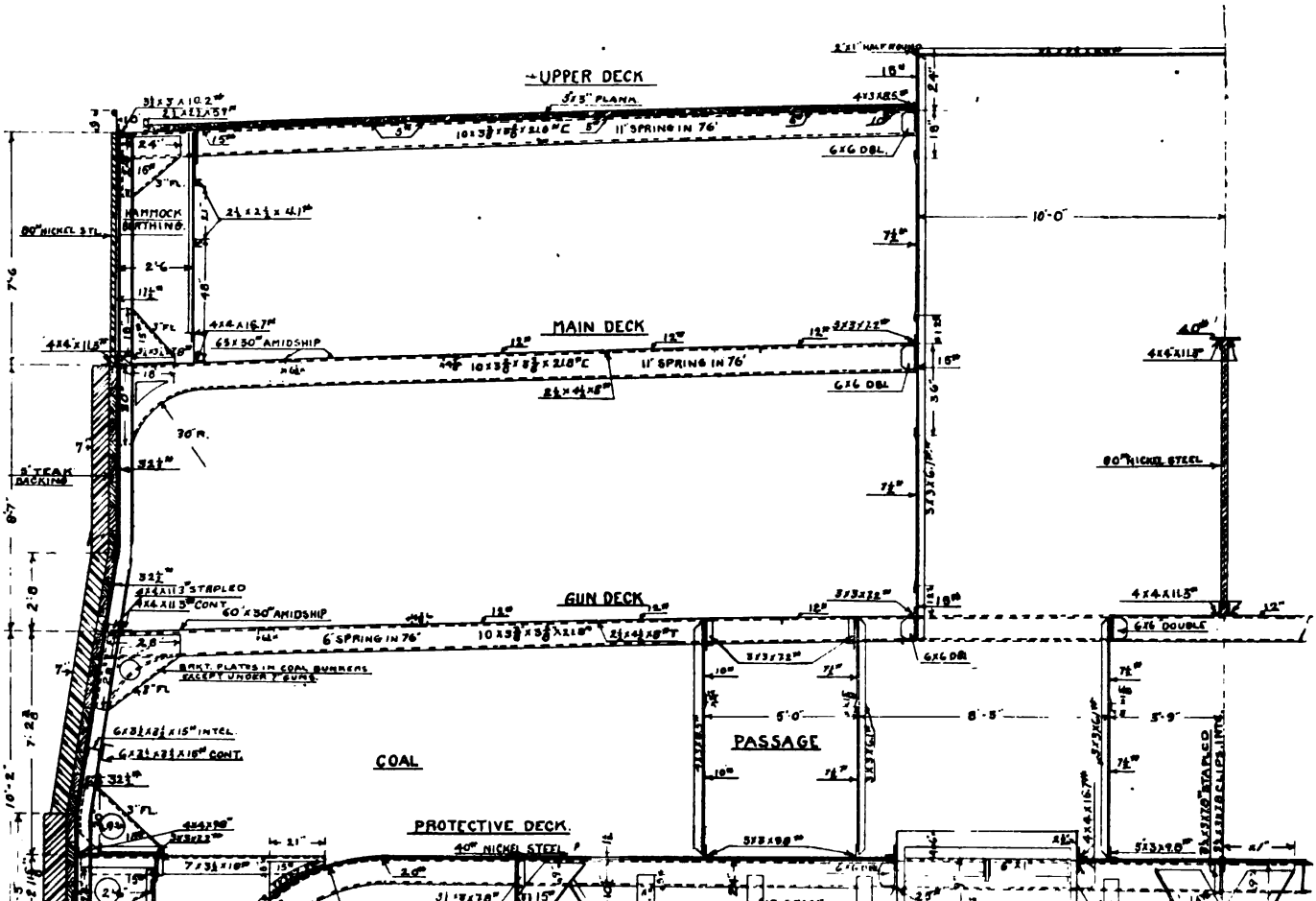

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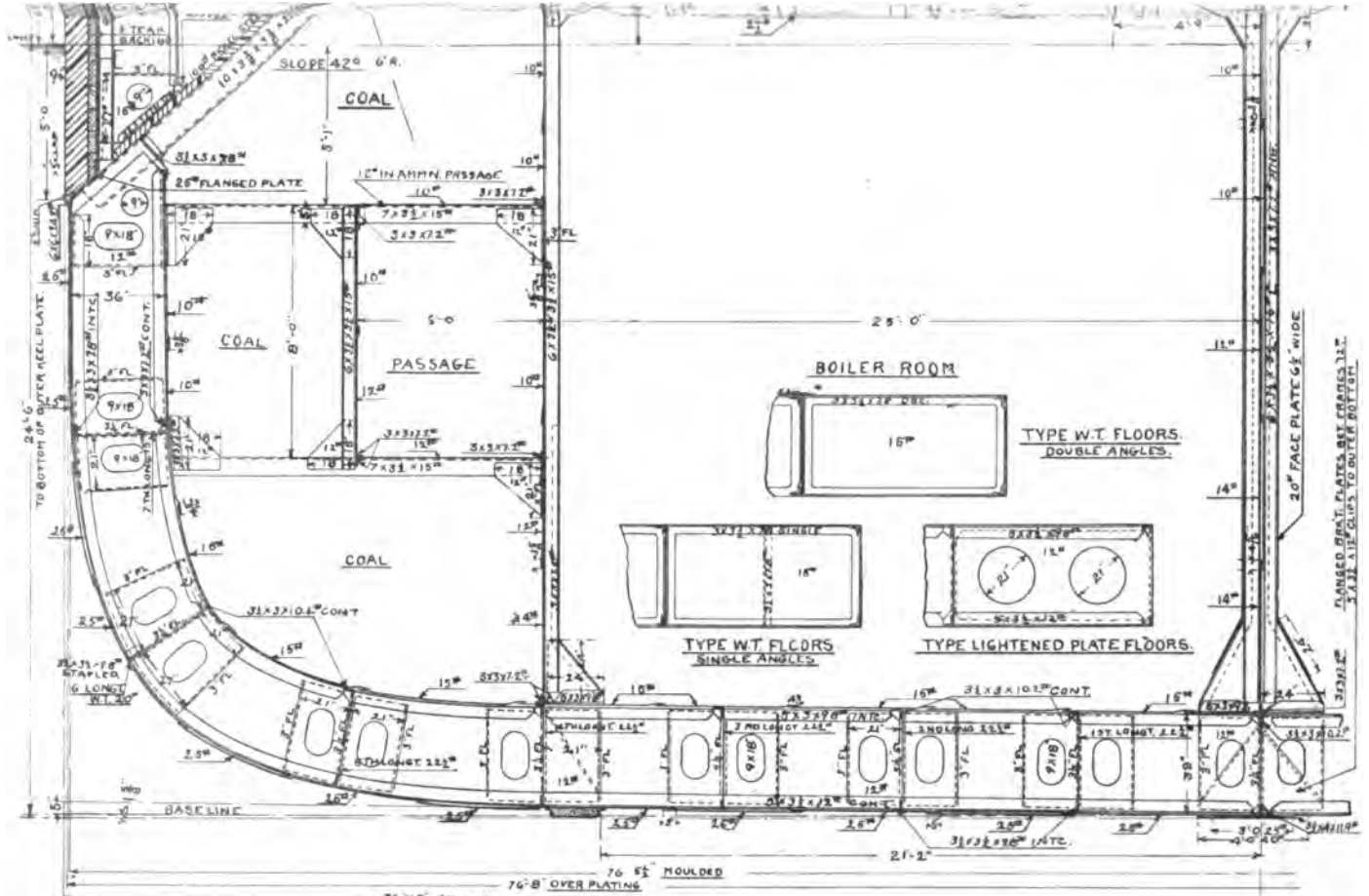

FIG. 78.—SECTION RECENT BATTLESHIP.

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The frame and reverse frame are as in the bracket type. The floor plate is 12-lb. The connections to longitudinals are by $3\frac{1}{2}'' \times 3''$ bars or by flanging the edges of the plates.

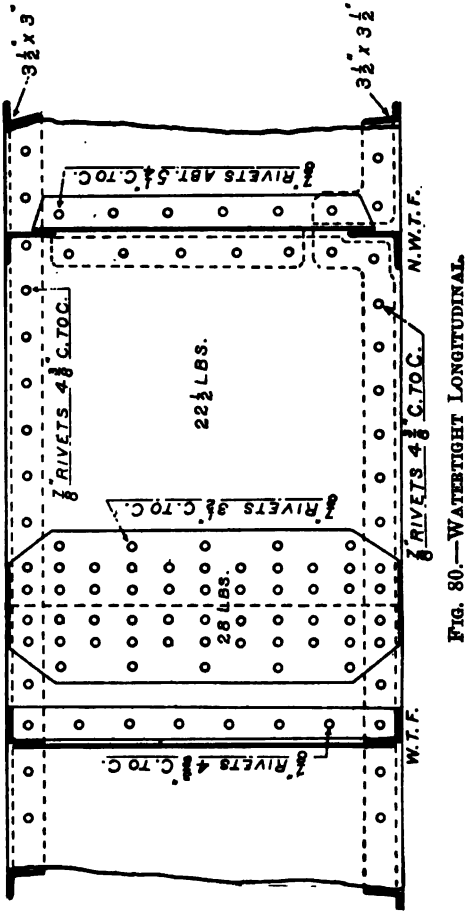

FIG. 80.—WATERTIGHT LONGITUDINAL.

The lightening holes are 21 inches diameter, round, generally two in each space.

Stiffening angles are fitted where necessary, and in special cases the thickness of the floor plate is increased.

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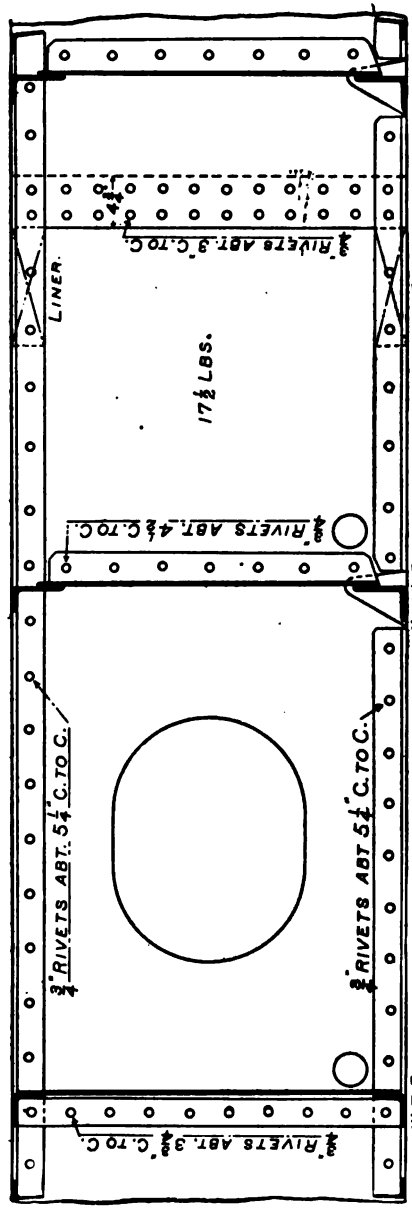

FIG. 81.—NON-WATERTIGHT LONGITUDINAL.

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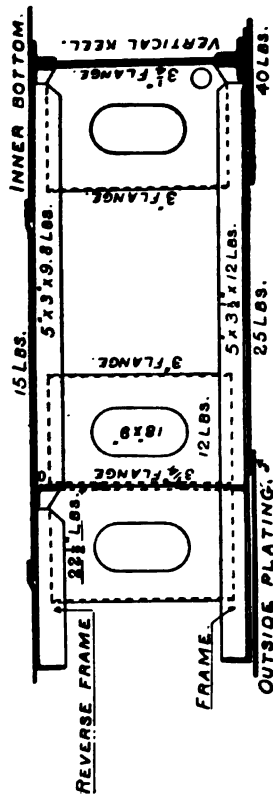

FIG. 82.—BRACKET FRAMES.

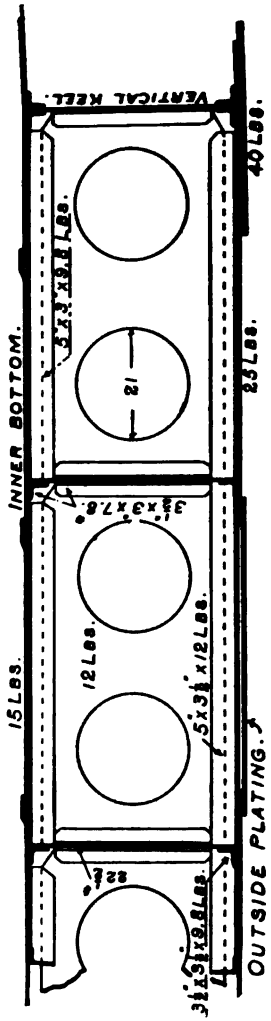

FIG. 83.—LIGHTENED FLOOR-PLATE.

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Watertight frames, with the watertight longitudinals, divide the inner-bottom space into a large number of watertight spaces. This frame is made of 15-lb. plate between vertical keel and watertight longitudinal, and 12-lb. plate beyond this. The plate is solid, and box-staple angles are worked around the edges and over the longitudinal bars, enabling a tight fit to be made and the whole closely riveted and calked. In wake of reserve feed-water tanks, the box-staple angles are fitted on both sides of the floor plates; elsewhere, only on one side.

Extra framing, both longitudinal and transverse, is worked under boilers and engines, if necessary to provide a rigid support.

Framing behind and above armor.—The type of framing behind armor is governed by the necessity for providing a rigid support to the armor. The amount of framing required depends somewhat on the thickness of armor to be supported, but recent experiments have indicated that the amount of framing formerly fitted was in excess of the actual needs.

The sketches in Figs. 79, 80, and 81 show the development of the framing behind armor from ships of the *Indiana* type to the later or *Vermont* type.

Framing at ends of ship.—The description up to this point has dealt with the framing over length of inner bottom. The ends of the ship are somewhat differently framed.

As the value of bending moment has fallen off, the question of longitudinal strength is not of such vital importance, and the main function of the framing is for supporting and stiffening the shell plating.

Here we find the transverse framing continuous from vertical keel to protective deck. The framing in a battleship is made of a $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$ channel, with a 12-lb. lightened floor and a reverse bar of angle section $3'' \times 3''$ worked on inner edge of floor plate and connecting to frame bar above turn of floor. The floor plate is connected to vertical keel and to longitudinals by $3\frac{1}{2}'' \times 3''$ angles, and to protective deck by 15-lb. bracket.

Where the frame bars pass through the platforms, the watertightness is obtained by working staple collars around the frames.

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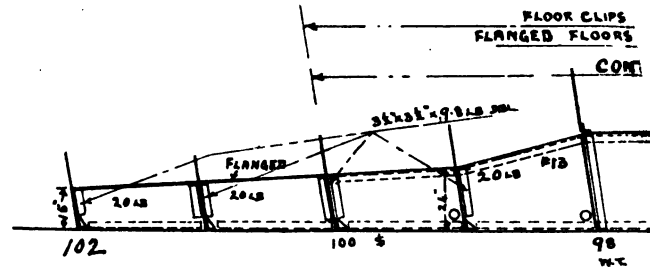

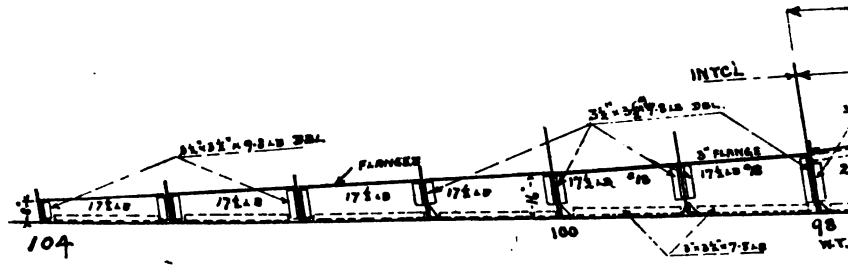

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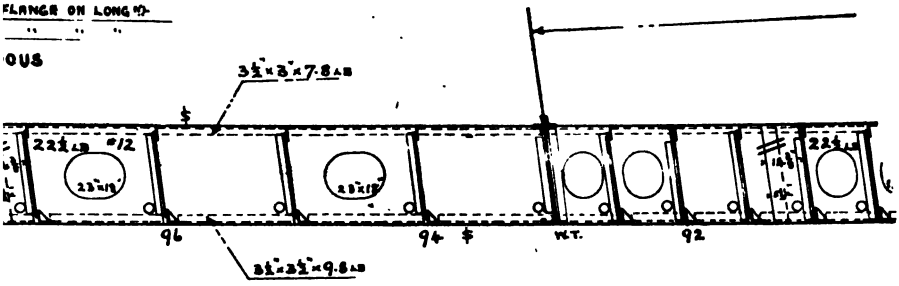

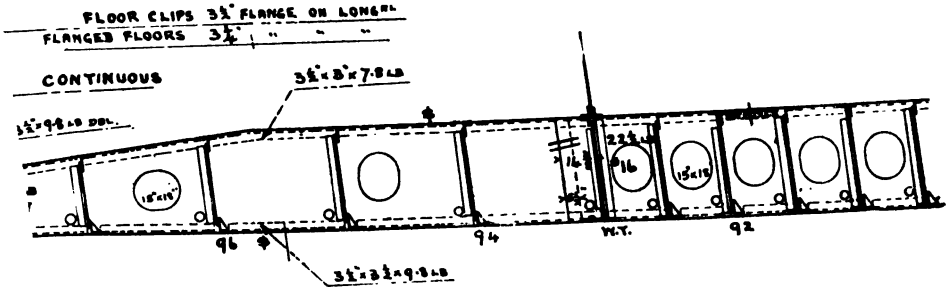

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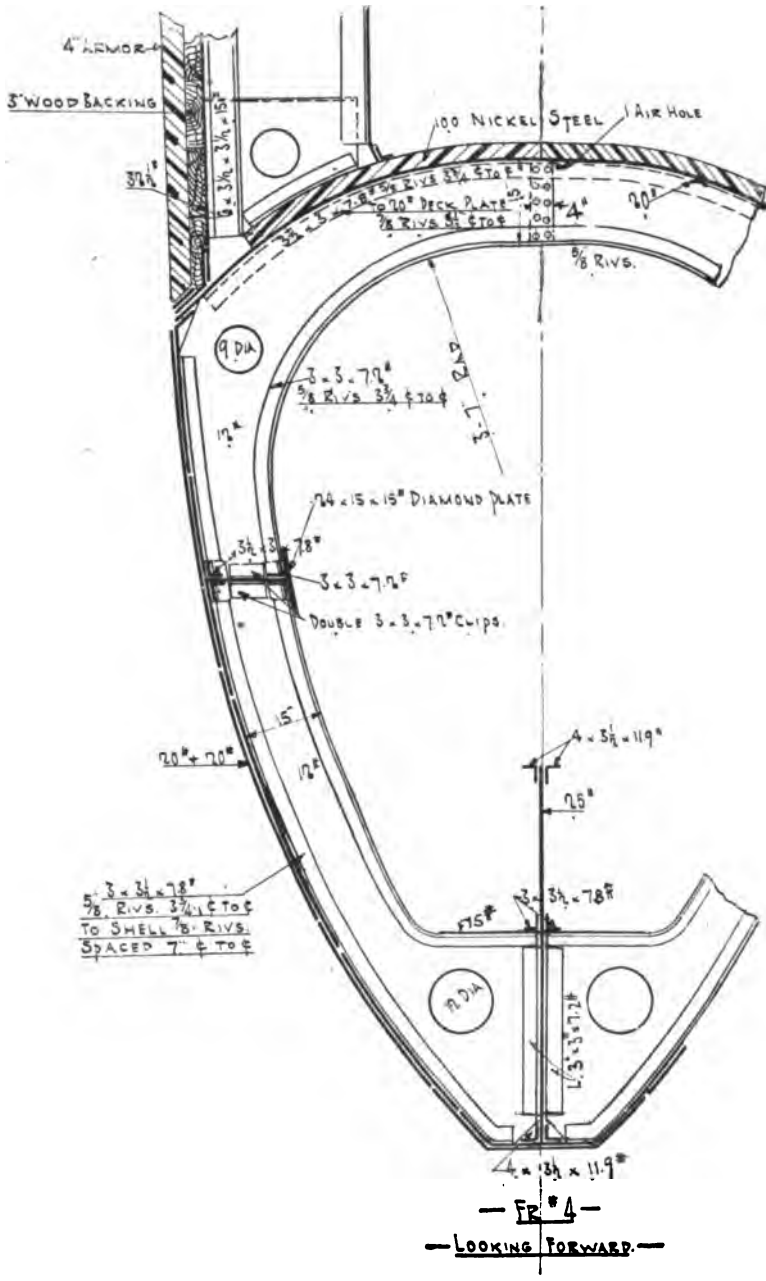

FIG. 85.—BOW FRAMING.

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The vertical keel, as before stated, is continuous from end to end of ship, attaching to stem at forward end and to sternpost at after end. The other longitudinals, however, are altered in character at ends. As the girth of the ship decreases, these longitudinals would get very close together; therefore it is usual to stop certain of them beyond the ends of the inner bottom, tapering them down to the form shown in Fig. 84.

The others are twisted so as to attach to a flat or to a fore and aft bulkhead. This arrangement of tapering some and continuing the others is necessary to prevent any discontinuity of fore and aft strength.

At the extreme forward end, forward of the collision bulkhead, which is a bulkhead near the bow for special protection in case of collision, the frame is made of deep web plates 15 inches deep, with a $3\frac{1}{2}'' \times 3''$ angle on outer edge, and inner bounding angle of $3'' \times 3''$. (See Fig. 85.)

Armored Cruisers.

The general broad distinction between this class of vessel and battleships has been indicated before, being one of greater speed and less armor and armament. The recent armored cruisers in the U. S. Service exceed in displacement the earlier battleships.

The following tabular comparison indicates, in general, this distinction:

	Battleships.		Armored Cruisers.	
	Alabama.	*Connecticut.*	*Pennsylvania.*	*Tennessee.*
Length	368′ 0″	450′ 0″	502′ 0″	502′ 0″
Breadth	72′ 2½″	76′ 10″	69′ 6½″	72′ 10½″
Displacement	11,552 tons	16,000 tons	13,680 tons	14,500 tons
Armor belt	16½″ top 9½″ bottom	11″ top 9″ bottom	6″ top 5″ bottom	5″ top 5″ bottom
Armament	4—12″ 14— 6″	4—12″ 8— 8″ 12— 7″	4—8″ 14—6″	4—10″ 16— 6″
I. H. P.	11,207	16,500	23,000	23,000
Speed	17 knots	18 knots	22 knots	22 knots

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The design of cruisers classed as armored cruisers has undergone radical changes in the last fifteen years. In the *New York* and *Brooklyn,* the protection was obtained by a sloping protective deck with thick plating, with a narrow belt of thin armor near the waterline, and coal protection. (See Fig. 86.)

The *St. Louis* class, now called *protected cruisers,* have a very considerably greater protection than the *New York* and *Brooklyn,* on the same displacement, as will be seen from Fig. 87.

The *Tennessee* class has a still more efficient protection of greater area, as shown, Fig. 88.

Taking the framing of the *Tennessee* class, 502 feet long by 72 feet 6 inches beam of 14,500 tons, we find it in principle identical with the battleships. The vertical keel is 39 inches deep, of 25-lb. plating, the top angles $4'' \times 3''$, and on the bottom, $4'' \times 4''$. The number of longitudinals on each side is the same as in the battleships. The transverse framing is substantially the same as in the battleships, both in size and arrangement. The framing in engine room is built unusually strong on account of the engine power, additional longitudinals being fitted in inner bottom in wake of engines, and intermediate transverse frames of lightened floor-plate are fitted here on the half frame spaces.

Framing of vessels of the large protected cruiser type (*Columbia*).—A typical section of such a cruiser is shown in Fig. 89.

Here the protective deck and the coal form the protection. The inner bottom is of somewhat less extent transversely than above. The vertical keel is 42 inches deep, of 20-lb. plates, with double angles at top $3\frac{1}{2}'' \times 3''$, and at bottom $4'' \times 3''$. There are 4 longitudinals on each side, 16 lbs., the fourth longitudinal being watertight and a side stringer is worked between the W. T. longitudinal and the protective deck. The inner bottom extends from frame No. 29 to frame No. 82, about half the length. For the transverse framing within the inner bottom, the outer bar is $5'' \times 3\frac{1}{2}''$ angle, the reverse bar is $5'' \times 3''$, the floor plates being $12\frac{1}{2}$ lbs., and of same general type as on battleships. At the date when this class was built, the flanged bracket floor was not in general use; otherwise the floors do not differ from present practice.

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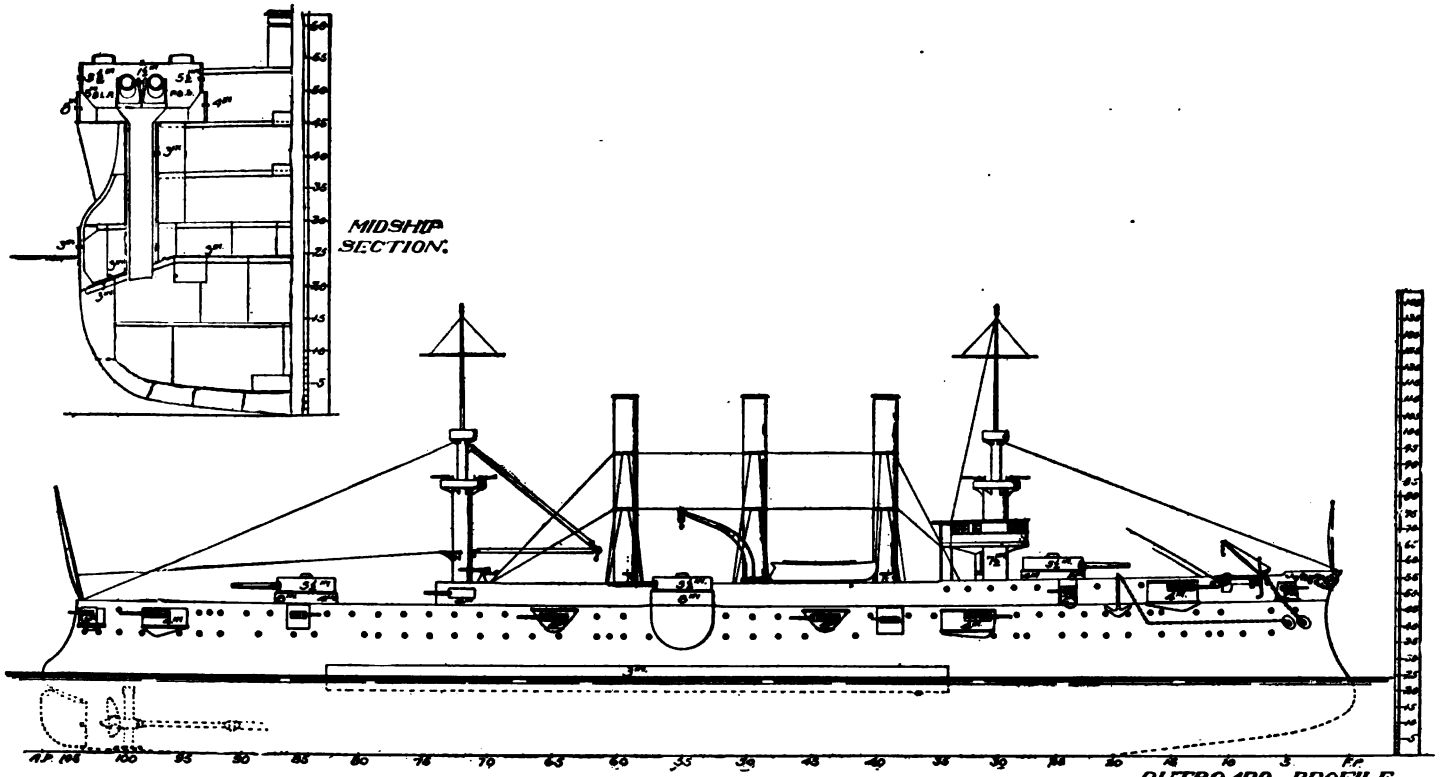

FIG. 86.—U. S. S. BROOKLYN.

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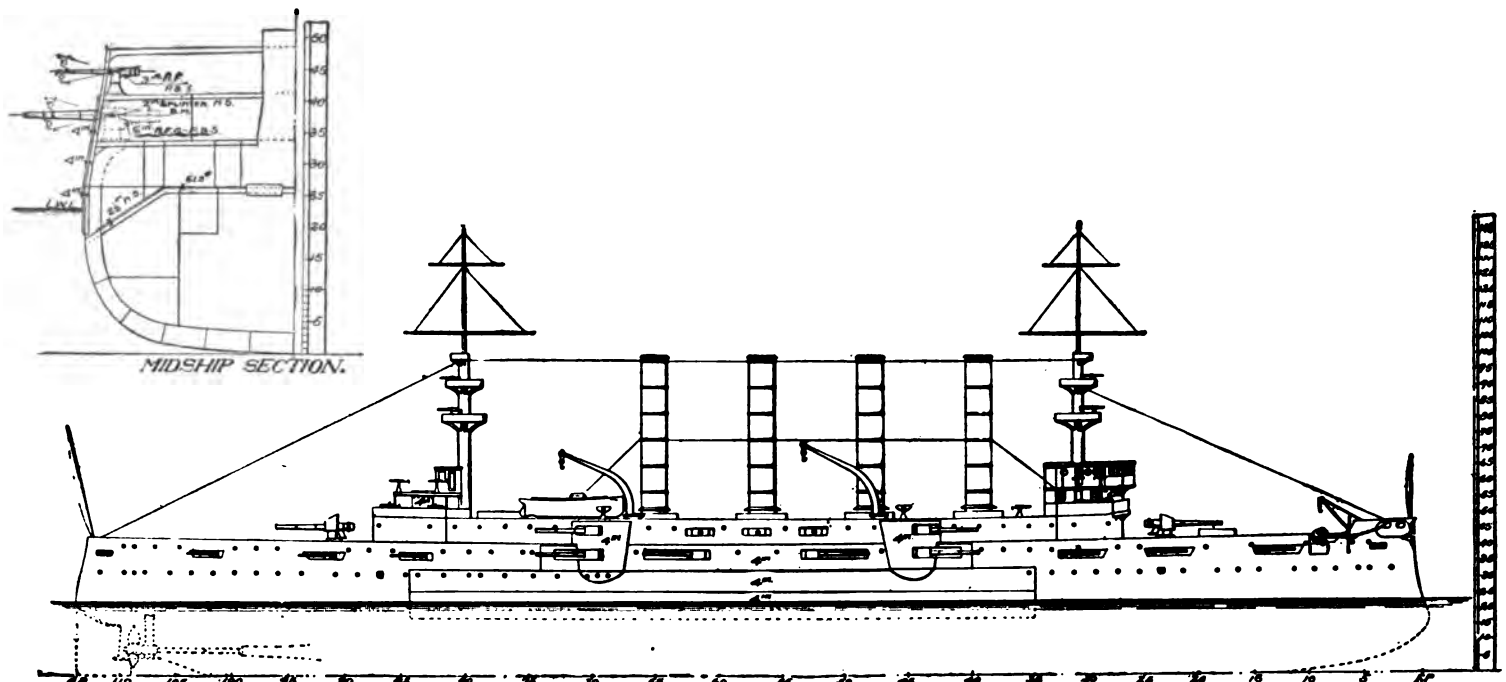

FIG. 87.—U. S. S. ST. LOUIS AND CLASS.

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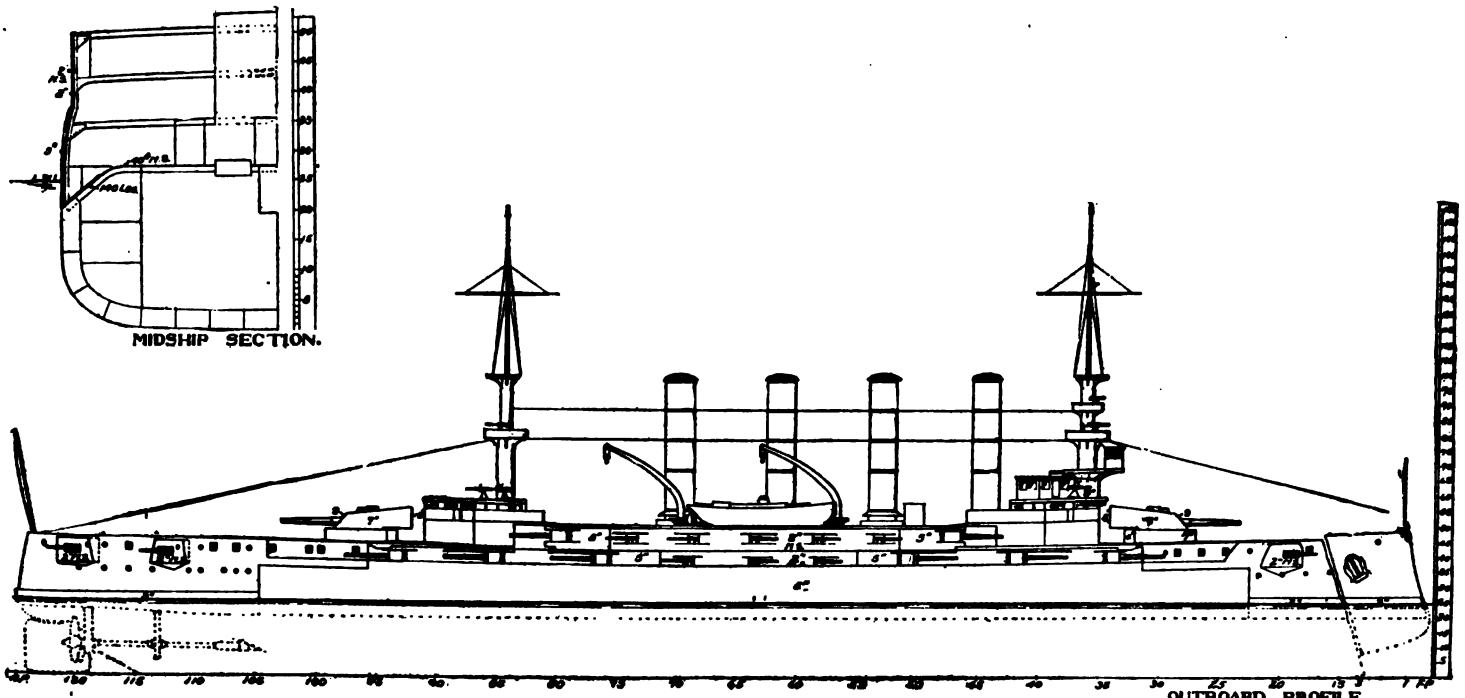

FIG. 88.—U. S. S TENNESSEE, WASHINGTON.

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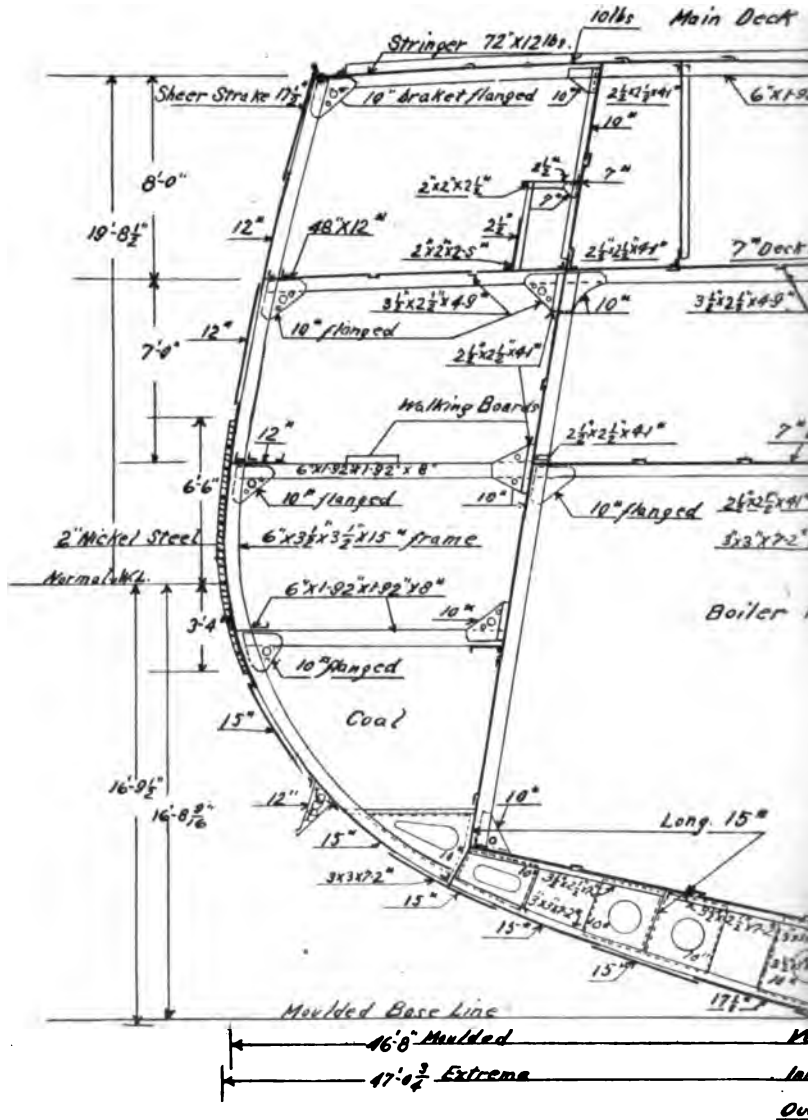

FIG. 90.—SECTIO

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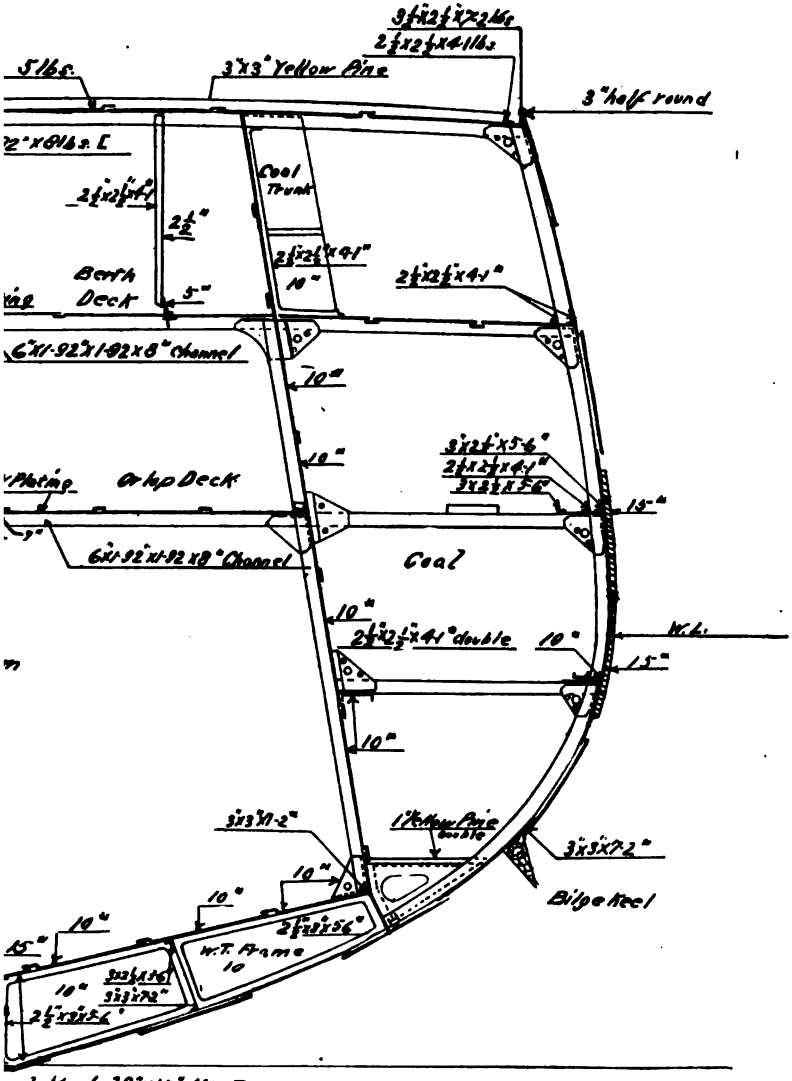

Keel 39"x15" N.W.I

Keel 17½"

Keel 20"

OF SCOUT CRUISER.

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From outer edge of inner bottom to protective deck, the frame is formed of an angle bar 5″ × 3½″ with reverse bar 4″ × 3½″, and a 15-lb. bracket riveted in at bottom to give attachment to the W. T. longitudinal, or as it is called in merchant ship building, the margin plate.

Forward and aft, beyond the limits of the double bottom, the framing is of Z-bars, 6″ × 3½″ × 3½″, continuous from vertical keel to protective deck, the lower ends split and opened out, and 10-lb. floor plates riveted in. Connection to vertical keel is by 3″ × 3″ angles, and the upper end is bracketed to the protective deck by 15-lb. plates. The framing at ends is spaced 3½ feet. Above protective deck the framing is of 6″ × 3½″ × 3½″ Z-bars in one length from protective deck to upper deck.

Scout Vessels.

These vessels, being built for special service, have special arrangements of structural features with a view of reducing weight to a minimum, while at the same time not sacrificing the strength of the structure. The general type of structure is as shown in Fig. 90. The vertical keel is 39 inches deep, of 15-lb. plate, worked continuous and non-watertight, with double angles at bottom 3½″ × 3″, and at top, 3″ × 3″. The frame spacing is 3 feet. The inner bottom extends from bilge to bilge and over engine and boiler spaces only. The frames within the inner bottom consist of a frame bar 3″ × 3″ and a reverse bar 3½″ × 2½″. The frame bar is continuous from vertical keel to margin plate or second longitudinal. Lightened flanged bracket floors of 10-lb. plate are fitted between frame and reverse bar, but under engines and boilers, lightened-plate floors are fitted instead. Outboard of second longitudinal, frames are of channels 6″ × 3½″ × 3½″, continuous from bilge to main and forecastle deck, bracketed to margin plate with 10-lb. lightened plate flanged and riveted to margin.

Forward and aft of double bottom, frames are 6″ × 2 13/16″ × 2 13/16″ channel, split at lower end, with 10-lb. plate fitted in and flanged to vertical keel. Belt frames, about 15 inches deep, of 10-lb. plate, fitted on regular channel frames and stiffened on inner edge with double 2½″ × 2½″ angles, are worked at intervals up to

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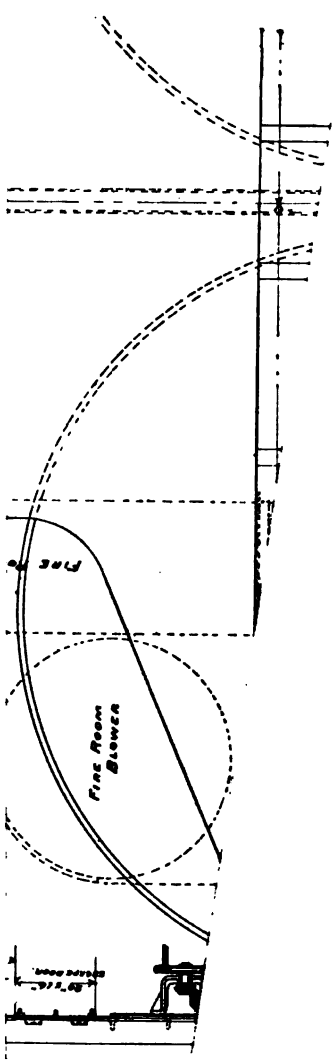

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platform deck, and intermediate frames are worked at half spacing in special localities.

There are two longitudinals on each side continuous, the second longitudinal being watertight.

Denver Class.

This class of cruisers, consisting of six vessels, constitute the only sheathed vessels in the U. S. Service, except the *Severn;* they are sheathed with wood, and coppered, to permit of service on foreign stations without the necessity for frequent dockings, which is necessary with unsheathed steel ships.

The midship section is as shown in Fig. 91.

Here the protective deck, coal, and cofferdams furnish all the protection. The inner bottom is retained, but is somewhat less in extent than before, being over about two-thirds of length, under magazine, engine, and boiler spaces. The inner bottom extends to the bilge on either side, as in the case of large cruisers, but there is no wing bulkhead, the coal bunker extending to the shell.

The vertical keel is continuous, 34 inches deep, of 15 lbs., with double angles at top, $3\frac{1}{2}'' \times 3\frac{1}{2}''$, and double angles at bottom, $4'' \times 4''$. There are three longitudinals on either side, two of $12\frac{1}{2}$ lbs., non-watertight, and the third of 15 lbs. and watertight.

The transverse framing is of Z-bars, $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$, from main deck down to and cut at turn of bilge and bracketed to margin plate. From margin plate at bilge to vertical keel, the frame bar is $4'' \times 3\frac{1}{2}''$ angle, and the reverse bar is $3'' \times 3''$ and lapping on the Z frame bar above turn of bilge.

In double bottom, flanged bracket plates of $12\frac{1}{2}$ lbs. are fitted from keel to second longitudinal, outboard of which the floor plate is of the lightened plate type.

Watertight frames are worked as necessary for subdivision. Two longitudinal girders or bilge stringers are worked above the turn of bilge, of a continuous Z-bar $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$, with intercostal plates attached to it and flanged and riveted to outside plating.

Framing at ends is of $4'' \times 3\frac{1}{2}''$ angles, continuous from keel to main deck, with reverse bar of $3'' \times 3''$ from keel to bilge.

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Dubuque Class.

This class is of composite construction, *i. e.*, with metal frames and wood planking. The general features of framing the structure present no novelties. The special features of this class, such as the limited extent of shell plating, the fastening of planking to frames, and the making of plank butts are treated in a later chapter.

The vertical keel is continuous, non-watertight, 30 inches deep, of 14-lb. plate, with double angles at top, $3'' \times 3''$, and at bottom $3\frac{1}{2}'' \times 3''$. The frame spacing is 20 inches, and the inner bottom extends only under boiler room.

In inner bottom and under engine room, the frame bar is $3'' \times 3''$ angle, with reverse bar $3'' \times 3''$, and lightened-plate floors of 12 lbs., the frame, reverse frame, and floor being continuous from vertical keel to margin plate. Above inner bottom, frames are of channels, $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$, continuous to main deck, split at lower ends and bracketed to margin.

Forward and aft of inner bottom and engine room, the frames are of $6'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$ channels, split at lower end, and 10-lb. lightened floor riveted in and flanged to keel plate. The frames are continuous to main deck.

There is no protective deck.

There are two longitudinals on either side, consisting of a continuous channel on inside of reverse frame, with intercostal pieces connecting them to shell. These intercostal pieces are of channel where depth from reverse frame to shell will permit, and elsewhere of plates riveted to the continuous channel and clipped to the shell with angles.

Special intermediate channels are worked under engine foundations.

Torpedo-Boat Destroyers.

The essential feature of this type of vessel is speed, and unusual effort is made to reduce weight to the lowest amount possible consistent with strength by use of special material and distribution of material. A typical section of a destroyer is given in Fig. 92.

The vertical keel is continuous, 10 lbs., and about 15 inches deep, with double angles at bottom, $2'' \times 2''$, and at top, $2'' \times 2''$.

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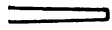
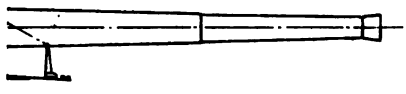
CRUISER.





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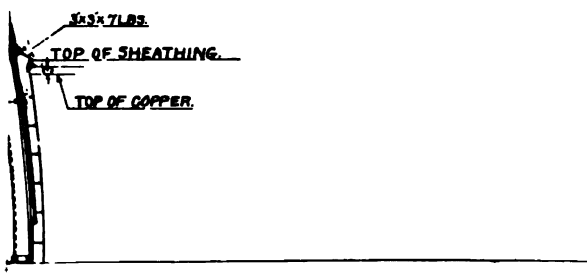

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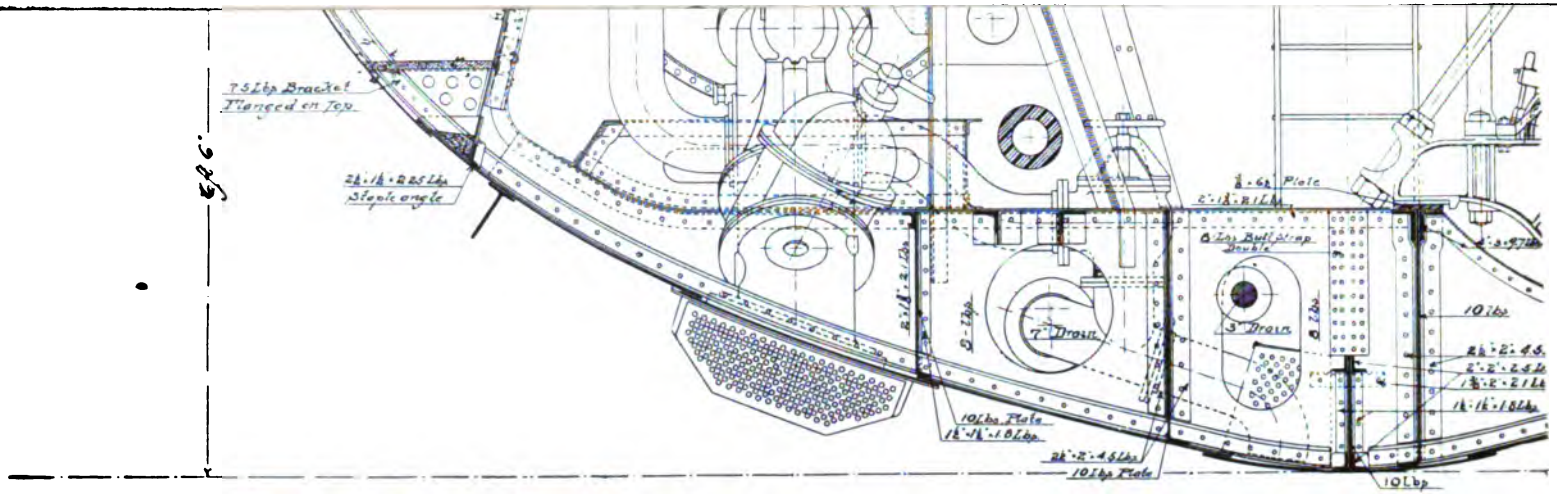

FIG. 92.—SECTION OF T.-B. DESTROYER.

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Butts double strapped and treble riveted. The frame spacing is 21 inches. Frame bars are of angle bulb, in one length from deck to keel, $2\frac{1}{2}'' \times 2\frac{1}{2}''$.

There is a floor plate on each frame, but of less depth than the vertical keel, except in wake of engine foundation as shown; these plates are 8 lbs. in engine and boiler spaces; elsewhere of 5 lbs.

The reverse bars are continuous from bilge to bilge, and worked on every frame, $2'' \times 1\frac{3}{8}''$ in engine and boiler spaces, $1\frac{1}{4}'' \times 1\frac{1}{4}''$ elsewhere. The outboard ends are turned up and riveted to the stiffeners of the coal-bunker bulkheads, as shown on section.

In wake of engines and boilers, to form foundations for these, the floors are increased in depth and specially stiffened.

The coal-bunker bulkheads, deck stringer and sheer strake, and the engine and boiler bearers are specially arranged to assist in providing longitudinal strength.

Special beams are worked as necessary.

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Constructions Pratique des Navires de Guerre, Croneau.
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Cours pratique de Construction Navàle, Gayde.
Cours de construction du Navire, Callou.
Cours pratique de Construction Navale, Doyere.

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CHAPTER XII.

DECKS, BEAMS, STANCHIONS, ETC.

The following system of nomenclature is adopted for the decks of United States Naval vessels:

Steel Vessels.

1. The highest deck, extending from the stem to stern, will be called the "main deck."

2. A partial deck above the main deck at the bow will be called the "forecastle deck"; at the stern, "poop deck"; amidships, "upper deck." The name "upper deck" will also be applied to such partial deck extending from the waist to either bow or stern, in which case the name "forecastle deck," or "poop deck," as the case may be, will not be used; though the terms "forecastle" and "poop deck" may be used in a general way to designate the corresponding portions of such upper deck.

3. When there is no deck above the main deck at the bow or stern, the terms "forecastle" and "quarter deck" may be used, in a general way, to indicate the portion of the main deck forward of the foremast or of the superstructure, and aft of the mainmast or of the superstructure, respectively.

4. A partial deck above the main deck amidships, the space under which is not enclosed, or consists of small compartments, will be called the "bridge deck." This term will not be applied to a simple connecting gangway between the forward and after bridges, or between a bridge and the "forecastle" or "poop deck."

5. The working bridges will be called the "bridge," the "forward bridge," the "after bridge," the "upper bridge," the "lower bridge," according to circumstances. A connecting gangway between the forward and after bridges or between a bridge and the "forecastle deck" or "poop deck" will be called the "fore and aft bridge."

6. The first deck below the main deck, which is used primarily for berthing purposes, and on which no guns, or light rapid-fire

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guns only are carried, will be called the "berth deck." This is usually the deck at or next above the waterline.

7. A complete deck on which guns are carried between the main deck and the berth deck will be called the "gun deck." If there are two such decks, then they will be called the "gun deck" and the "lower deck," respectively.

8. A partial deck below the berth deck, if located on or above the "protective deck" or the "watertight deck" will be called the "orlop deck"; if below the "protective deck" or the "watertight deck," it will be called the "platform." If there are two platforms at different levels, they will be called the "upper platform" and the "lower platform." Where no "protective deck" or "watertight deck" is fitted, the same nomenclature will be followed, the next below the berth deck being called the "orlop deck."

9. A deck of extra strength and thickness of plating worked for protective purposes will be called the "protective deck." Where such deck is stepped a complete deck height, the respective portions will be called "middle protective deck" and "forward (or after) protective deck," when it is desired to distinguish between them.

10. The deck with sloping or curved sides in smaller vessels, worked similarly to a protective deck, but not of extra strength and thickness above the structural requirements, will be called the "watertight deck."

11. A deck worked for protective purposes below a protective deck will be called the "splinter deck." This applies to a separate construction only, and not to plating worked on lower side of protective deck beams.

12. A deck that is stepped less than a deck height will be named the same as though it were continuous.

13. Deck space will, in general, take the name of the deck above which it is situated. The space above a "protective deck" or "watertight deck" will not, however, be named from such deck, but will receive its name from the actual use to which such space is put. Thus, if the "berth deck" coincides with the "protective deck," the latter term will only be used in referring to the structural features of the deck itself, but the space above it will receive its name from the "berth deck." Similarly, an "orlop

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deck" coinciding with a "protective deck" gives its own name to the deck space. When neither of these decks coincides with the "protective deck," the space above the latter will be called "storerooms," "upper coal bunkers," etc., as the case may be.

Wooden and Sailing Vessels.

1. The old nomenclature will be adhered to in referring to the decks of wooden vessels and vessels with full sail power.

Beams.

The transverse framing ends at the main deck, or in ships whose quarter deck is cut down, at the main deck aft and the upper deck

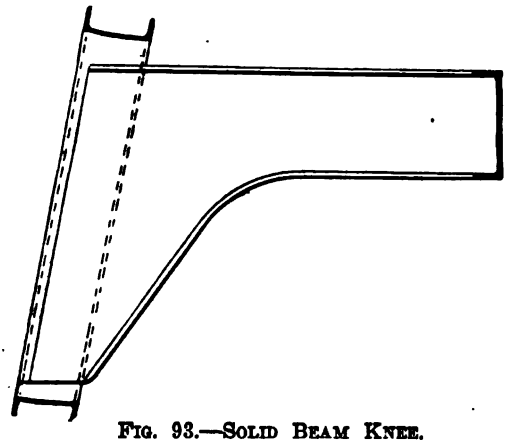

FIG. 93.—SOLID BEAM KNEE.

from the break to the bow. The upper ends of the frames are fastened together from side to side by beams. This completes the transverse structure. Beams are also introduced, tying the frames together from side to side, at the level of the various decks and platforms, and form supports therefor.

Beams for weather decks, or decks on which water is liable to come, are given a camber or round. For large ships of 70 to 75 feet beam, this is usually 11 inches, and for small ships of 50 feet beam, about 6 inches.

Beams to protective decks having sloping sides are level in the middle, and given a slope of from 30° to 40° at the side.

The beam spacing for large ships in the U. S. Service is 4 feet,

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sometimes reduced at ends to 3½ feet or 3 feet. For scout ships and similar vessels it is 3 feet, and for torpedo-boats it is 21

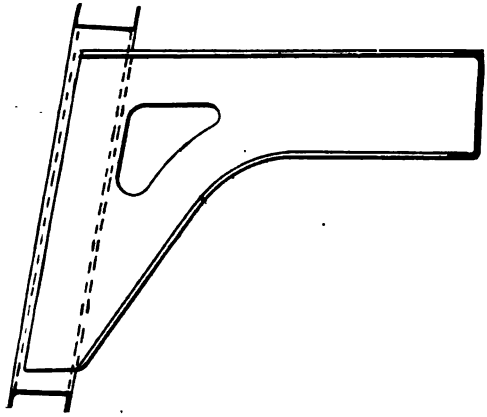

FIG. 94.—LIGHTENED BEAM KNEE.

inches. It is usual in the U. S. Service to put a beam on each frame.

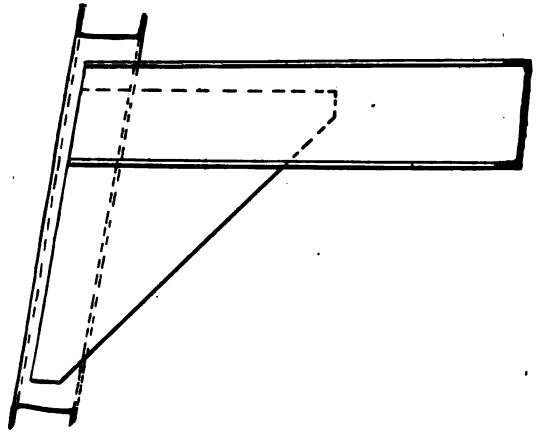

FIG. 95.—BRACKET.

Beams in the U. S. Service were formerly, for all ships, of the angle bulb section. Latterly, beginning with the *Connecticut* class, the channel section has been used exclusively, except for flats

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not required to support much weight or water pressure, where angles are used.

The connection of the beam to the frame is of great importance to withstand the racking due to rolling of the ship. Beams are connected to frames either by by lightened beam knees, solid beam knees, or brackets. Beam knees are used where appearance is

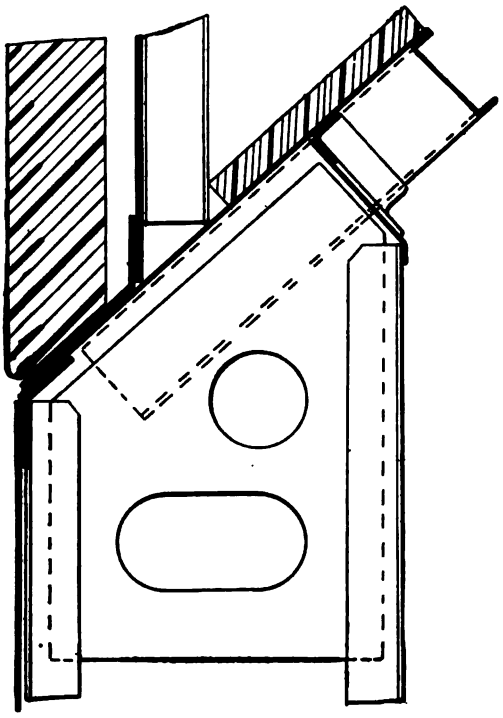

FIG. 96.—PROTECTIVE DECK BEAM CONNECTION.

desirable, being generally lightened, except under gun foundations and concentrated weights. A beam knee is formed by splitting the beam at the middle of the web, and bending down the lower flange and welding in a piece of plate. Brackets are used elsewhere.

Protective deck beams are connected to inner bottom floor plates by simply lapping a good distance and riveting.

Sketches of these are given above. (Figs. 93, 94, 95, and 96.)

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Beams often require to be cut for hatches or the openings in the deck. The inner ends are then connected together and to the next adjacent continuous beams by fore and aft *carlings*.

Carlings are generally formed of the same section as the beams,

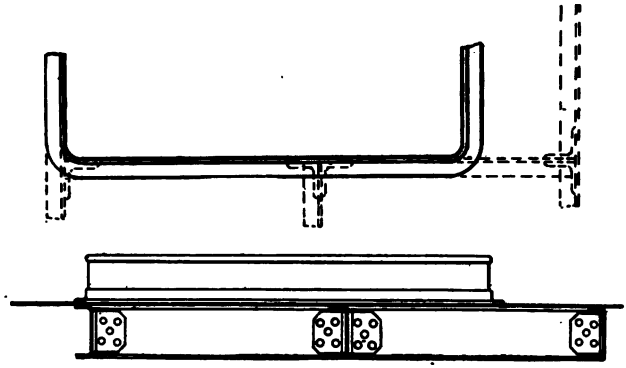

FIG. 97.—CARLING.

though sometimes made of heavy plate of some depth where the opening is large, to compensate for the loss of strength, or of a heavy plate in connection with a section equivalent to the beam. (See Fig. 97.)

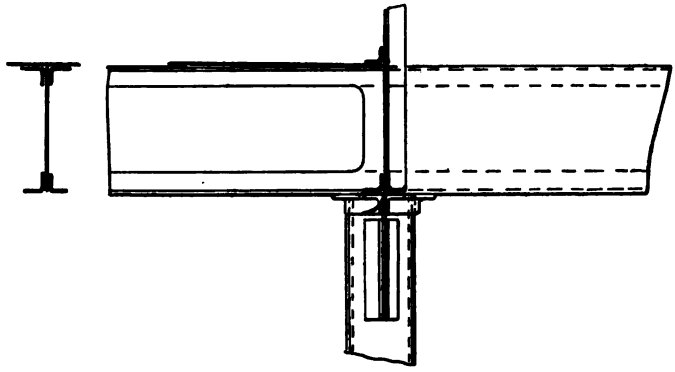

FIG. 98.—STRONG BEAM.

In the case of unusually large openings, as for cargo hatches in colliers, or for funnel openings, built-up strong beams of special section are employed and supported by stanchions. (See Fig. 98.)

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Under gun foundations special beams or double beams, back to back, are often employed.

Stanchions.—The beams of a broad ship, being of considerable length, require to be supported at other places than their ends. In the U. S. Service it is customary to have no greater unsupported

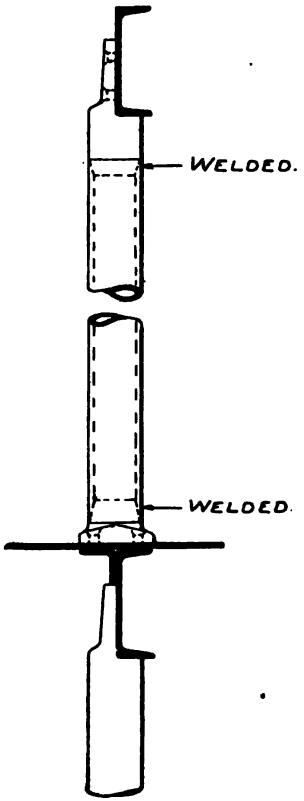

FIG. 99.—STANCHIONS.

length than 18 feet. Where possible, the ship's bulkheads are employed as intermediate supports. The vertical supports are called stanchions and are usually formed of iron pipes with solid heads and heels welded in, though sometimes of special and built-up sections, the form employed being the one to give a maximum of rigidity with a minimum of weight. (See Fig. 99.)

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Stanchions are so arranged and located as to form continuous vertical supports from upper deck to protective deck or to inner bottom, the fastening of the ends being directly to the metal beam or deck, and not to plank or other deck covering which may be fitted.

Portable stanchions are sometimes fitted where interference is apt to occur, but in recent years this is seldom done.

Deck plating.—Plating is worked on decks and flats for several reasons:

(1) Contributing to structural strength, as on upper or strength deck.

(2) For protection against missiles, as on protective deck and splinter decks.

(3) To divide ship into horizontal watertight layers.

(4) To support various auxiliaries, fittings, and structures.

(5) To protect against fire.

(6) To provide walking flats so as to best utilize the space.

Main or strength deck.—The main deck, as seen by the definition, being the upper continuous deck, is usually the strength deck, but in vessels similar to the *Alabama* class, whose quarter-deck is lowered, the strength deck becomes the upper deck; it forms the upper flange of the girder and contributes very largely to the girder strength. (Fig. 100.)

The strake of plating at the side is called the *deck stringer.* In the deck shown in Fig. 100 it is 30 lbs. and 12·4 inches wide. The two outboard strakes, as in this case, are often combined to form the stringer.

Doubling plates are also worked around hatch and other openings, to compensate for loss of strength, generally of 12 to 20 lbs., depending on location.

The weight of plating of this deck, between stringers, in general, is 12 lbs.

The plating is laid directly on the horizontal beam flanges. It generally has single-riveted edge strips on upper side for that part of deck to be later covered with wood, and T-bars worked intercostally on underside between the beams for that part to be later covered with linoleum, so as to form a flush upper surface.

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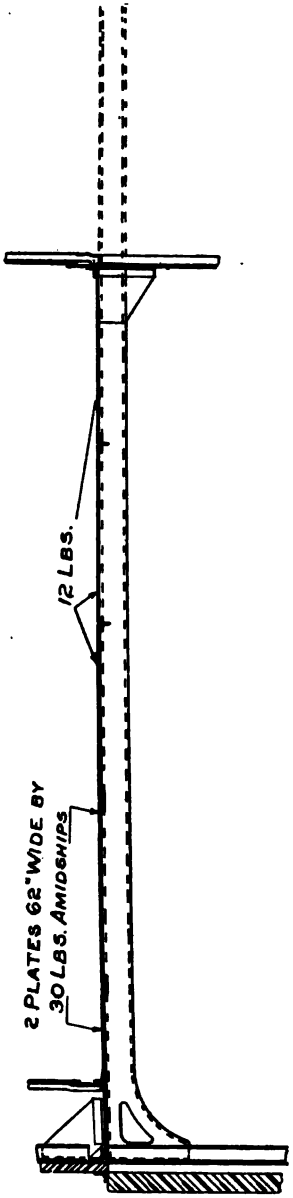

FIG. 100.—MAIN DECK.

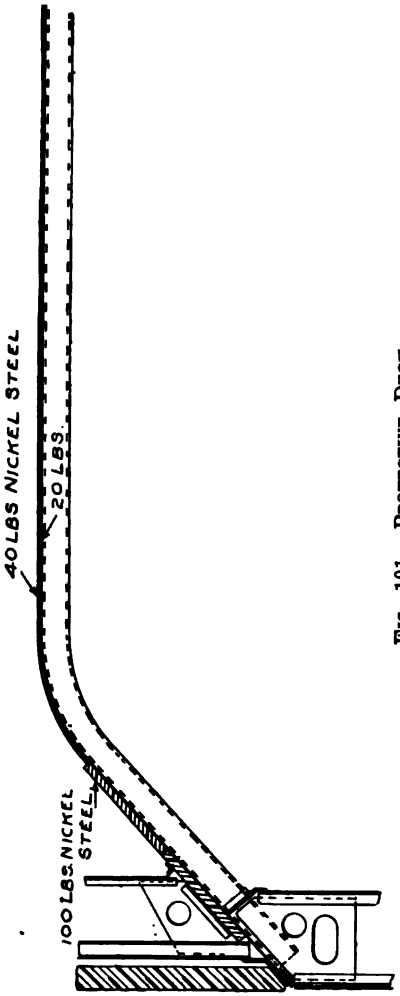

FIG. 101.—PROTECTIVE DECK.

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For the light plating, single butt straps on under side, double riveted, are fitted. For the stringer, single straps, quadruple riveted, are fitted.

Holes for coal scuttles, deck scuttles, deck lights, etc., are carefully compensated for by doubling plates.

The butts of plates in adjacent strakes are shifted clear of one another, and particularly clear of the butts in the sheer strake.

Protective decks.—In decks fitted for protective purposes, the plating is worked in two or more thicknesses. In early ships, and up to and including the *Maine* class, this was formed of two courses of 20-lb. plates, one on top of the other, and having their butts and seams so shifted that one course formed butts and seam straps of the other. On top of this was put the nickel steel protective plating varying in thickness from 40 lbs. to 120 lbs., according to location. In our later ships, the lower course is built like an ordinary deck, with butt and seam straps underneath and the nickel steel put on top of it. In the first-named method, the two lower strakes were fastened to the beams, and the upper course fastened to them by rivets around the edges of the plates and certain tack rivets throughout its area. In the later method, the lower course only is fastened to the beams, and the upper course to it.

The general arrangement is as shown in Fig. 101:

It is necessary that there should be no openings between the upper and lower course. Therefore, after completing the structure, it is customary to pump in red lead putty to fill all existing interstices.

Flats and platforms are generally plated with 10-lb. plates and fitted with single-riveted flat seam straps and double-riveted butt straps, both worked on under side of deck to allow fair upper surface.

Special flats, as in dynamo rooms and submerged torpedo rooms, are made with ribbed plating.

Watertightness of decks.—In watertight decks, the connection of the deck plating to inner bottom, bulkheads or shell plating must be watertight. The two sketches below show the method, (1st)

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where channel frames go through, (2d) where angle frames or stiffeners go through. As all these have to be subjected to water pressure, the work must be secure. The bars are smithed around and the riveting closely spaced and the whole calked. (See Figs. 102 and 103.)

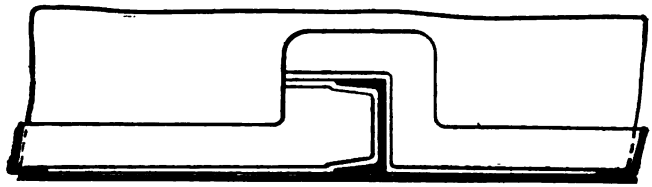

FIG. 102.—WATERTIGHT STAPLING AROUND CHANNEL FRAME.

Where transverse frames do not go through the flat, a fore and aft angle can be run along and calked.

Wood decks.—In the U. S. Service, are used only for weather decks, bridges, and boat decks. Formerly, wood was used for lower decks and often laid without plating. Now it is, in practically all cases, laid on top of plating.

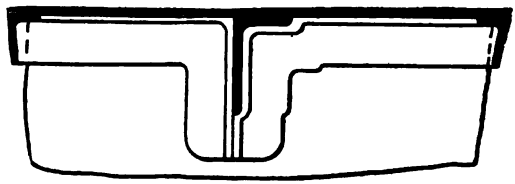

FIG. 103.—WATERTIGHT STAPLING AROUND ANGLE FRAME.

Wood weather decks are, in the U. S. Service, of $3\frac{1}{2}'' \times 3\frac{1}{2}''$ long leaf yellow pine on main deck; of $3'' \times 3\frac{1}{2}''$ on upper deck, and $2\frac{1}{2}'' \times 3''$ on bridge deck. These are in a few instances of teak, which, however, is an imported wood and hard to obtain.

Where the deck is laid on plating, the plank is secured to plating by through bolts, two bolts in each frame space of 4 feet, and in addition, if required, by certain lag screws from underneath. In certain special cases, decks are laid without plating, and then

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a strip of plate is riveted to the beam and the ends of the plank bolted to this as close to the beam as practicable. (See Fig. 104.)

Deck bolts are galvanized iron, with round head and square neck under the head; they are $\frac{5}{8}$" or 9/16" in diameter, depending on thickness of plank; they are fitted with a grommet under head, soaked in white lead, and also under washer at point. The head is recessed in a round hole and the hole filled with a plug bedded in white lead, the grain of the plug running in same direction as that of plank.

The planks before laying are slightly out gauged and the seams calked with (for main deck) four threads of oakum, forced down

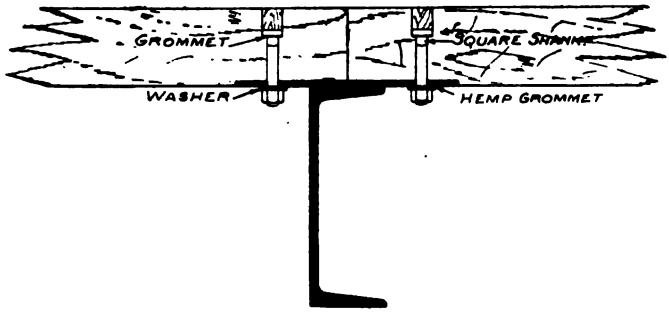

FIG. 104.—METHOD OF FASTENING DECK PLANKING WHERE THERE IS NO PLATING.

into the seam leaving a seam $\frac{3}{4}$" deep, which is then payed with marine glue.

In living spaces, linoleum is fitted, the steel deck under being kept flush for this purpose. This is fastened down with glue. Around edges, this linoleum is fastened by brass strips screwed to plating. In galleys, bath rooms, wash rooms, etc., tiling is fitted, bedded in Portland cement 2" deep.

In wake of doors, at foot of ladders, etc., non-slipping treads of lead and bronze are fitted. In special places, rubber tiling, wood gratings, and other special coverings are fitted.

The *hatches* in ordinary decks are of two types,—flush, or raised.

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The following two sketches (Figs. 105, 106) show these types in the U. S. Service:

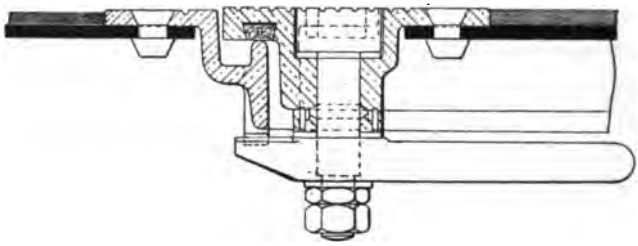

FIG. 105.—FLUSH WATERTIGHT HATCH.

Care should be given to rubber gaskets used for purposes of watertightness, and no paint should be allowed to touch the rubber. When the rubber is hard, it should be renewed.

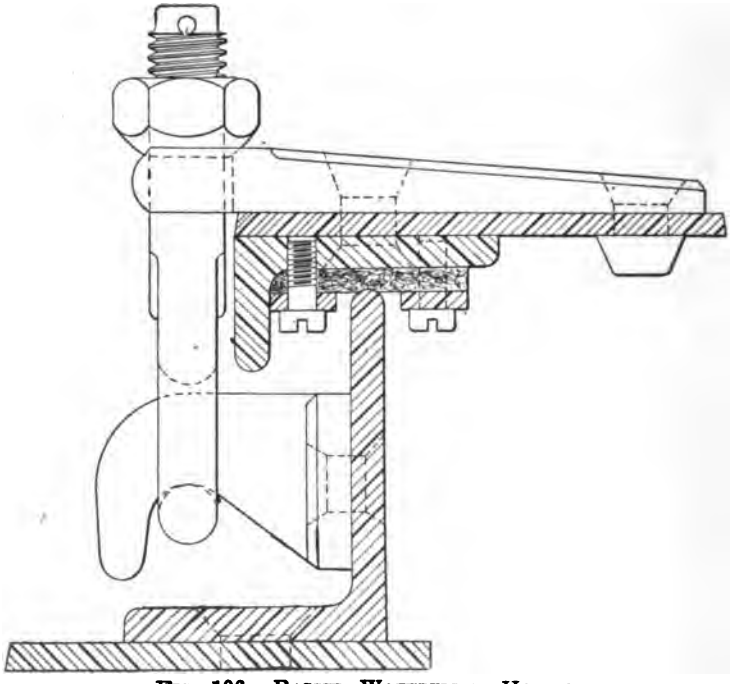

FIG. 106.—RAISED WATERTIGHT HATCH.

NOTE.—For references to this and succeeding chapters on structural work, see those given at end of Chapter XI.

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CHAPTER XIII.

OUTSIDE AND INNER BOTTOM PLATING.

Outside bottom plating.—This is the most important part of the structure, contributing largely to the structural strength and insuring watertightness; it also forms a considerable portion of the weight. The advantage of making the outer bottom of mild steel comes from its ductility, permitting considerable deformation by grounding or shock without fracture.

Shift of butts.—It is important in connection with the longitudinal structure of a ship to arrange for a good *shift of butts.*

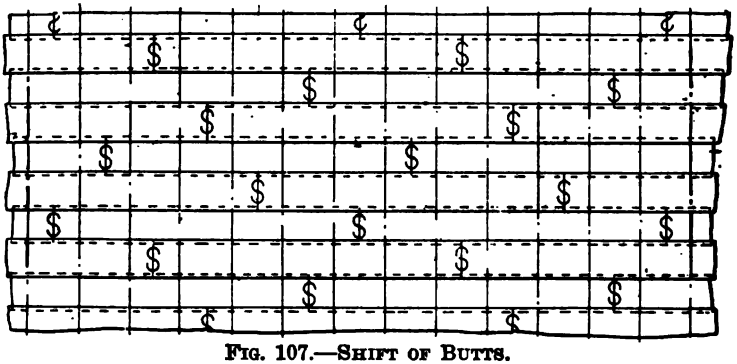

FIG. 107.—SHIFT OF BUTTS.

A butt is a place of relative weakness, and butts of the adjacent strakes and of the various portions of the structure should be kept well clear of one another. For shell and inner bottom plating, butts in the same frame spaces are not permitted to be closer together than two passing strakes, except at the ends of the ship, where, owing to decrease in girth, it becomes necessary to drop some strakes and where the decrease in stress does not make it a matter of such great importance. As it is now practicable to obtain and work steel plates 20 feet to 24 and 28 feet long, this requirement is not too onerous. With a 24-foot plate it is possible, in 4-foot frame spacing, to get five passing strakes (Fig. 107).

This principle should also be borne in mind in arranging butts of vertical keel, longitudinals, etc., to avoid weakness of structure.

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Plating of a battleship.—The outer bottom plating of a battleship is made 25 lbs. for about three-fifths of length, reduced to 22½ lbs. at end.

The fore and aft rows of plating are called *strakes.* In the same strake, the ends of these plates are lapped and treble-riveted, except the strake next below the protective deck, which is fitted with a single 30-lb. butt strap inside, treble-riveted, with alternate rivets in outer row omitted.

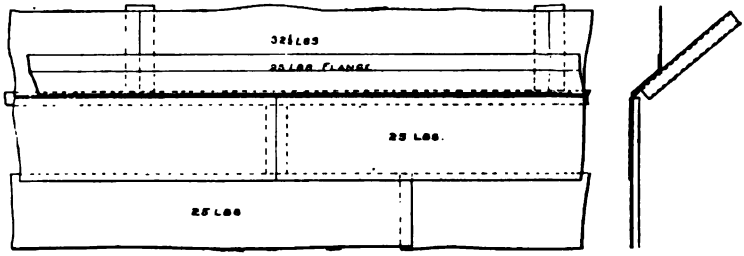

FIG. 108.—OUTER BOTTOM PLATING.

The adjacent strakes are worked on the *raised* and *sunken* system, the laps being double-riveted (Fig. 108).

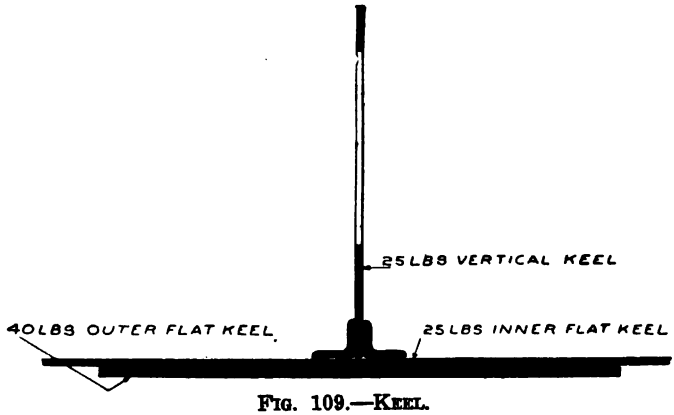

FIG. 109.—KEEL.

At every frame in way of outside strake or raised strakes, a liner is fitted to get good riveting between frame and plate.

At middle line, an additional outside plate of 40 lbs. is worked, called *outer flat keel,* the inner plate being the *inner flat keel* (Fig. 109).

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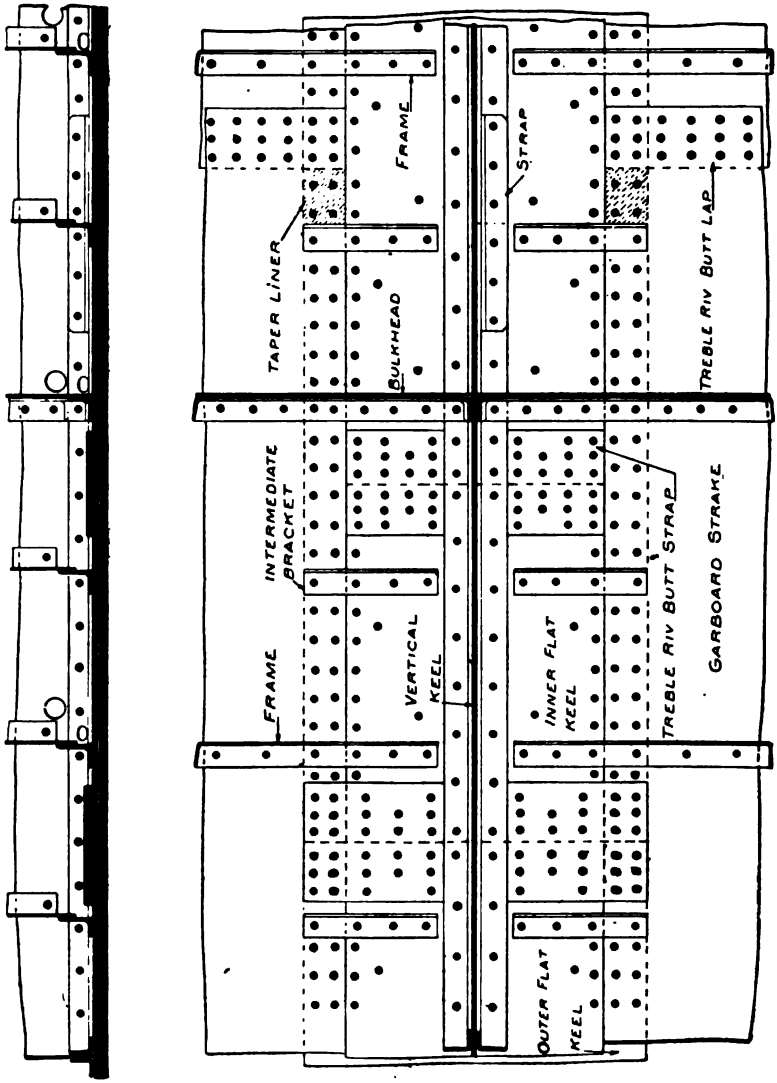

FIG. 110.—RIVETING IN OUTER BOTTOM.

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Riveting in outer bottom.—In Fig. 110 there will be seen, in some detail, the riveting, etc., in the outer bottom near middle line.

The lower angles of the vertical keel are connected to flat keels by 1-inch rivets. In the U. S. Service the vertical keel is not watertight; therefore, these rivets are spaced 7 to 8 diameters.

The longitudinals standing perpendicular to the outer bottom are not watertight, except No. 6, which is watertight throughout, and Nos. 3 and 5, which are watertight over a part of their length only, to form boundaries for reserve feed-water tanks. At ends where the girth is reduced, the watertightness is sometimes shifted from No. 6 to some other longitudinal.

Where longitudinals are watertight, close spacing for the rivets in their bounding angles is necessary.

The butt straps of inner and outer flat keels extend from keel angles to edges of plates connected, and are treble-riveted, with

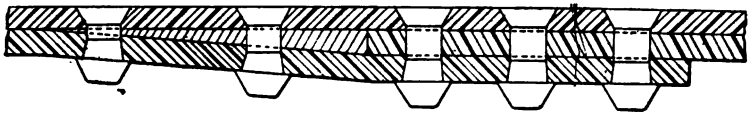

FIG. 111.—TAPERED LINER IN BUTT LAP.

alternate rivets in outer row omitted. Size of rivet, $\frac{7}{8}$-inch for straps of inner keel, and 1-inch or $1\frac{1}{8}$-inch for straps of outer keel.

The edges of the inner keel plate are single-riveted to outer keel plate, and the edge of the outer keel plate is double chain riveted with $\frac{7}{8}$-inch rivets to the garboard strake, *i. e.*, the next adjacent strake to the flat keel.

The remainder of the shell riveting is with $\frac{7}{8}$-inch rivets.

At the butt laps of plates in inside strakes, taper liners are fitted in the seams (Fig. 111).

The ends of the plates if not lapped are butted and fitted with single butt straps, double-riveted for inside strakes, extending the full width of plate; for outside strakes, extending from edge to edge of adjacent inside strakes.

The ordinary frames are connected to the shell plating by $\frac{7}{8}$-inch rivets, spaced 8 diameters, but for watertight frames this spacing is 5 diameters. This close spacing cuts away considerable ma-

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terial and it is customary to compensate for this by fitting on the raised strake a lozenge or bulkhead liner, by which the strength is brought up to that of an ordinary frame. Where a watertight frame comes next to a butt strap, the butt strap is usually extended to form a liner. Fig. 112 shows a combined bulkhead liner and butt strap.

Plating behind armor.—Above the protective deck the side plating is recessed back from the side of the ship to allow for armor and backing without having a projecting overhang (see Fig. 77).

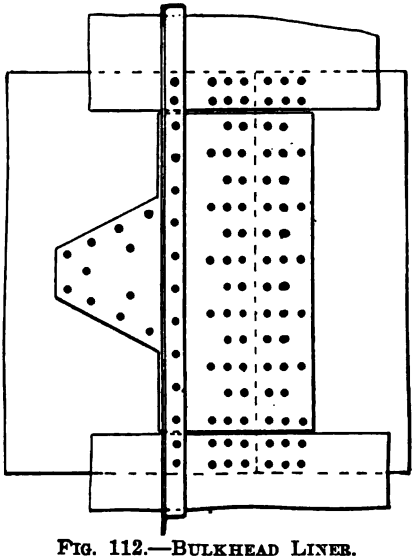

FIG. 112.—BULKHEAD LINER.

This plating is made of 32½ pounds behind armor. Above the armor, where the armor stops short of main deck, and beyond it, at ends, the plating is reduced to 20 pounds, except where greater thickness is required for strength. Behind armor, this plating is worked close against the frames, with double-riveted continuous-seam straps on the outside. The butts of this plating have 40-lb. straps on the inside, quadruple-riveted, with alternate rivets in outer row omitted. Above the armor and beyond the ends of the armor, the plating is worked with continuous seam straps on inside, double-riveted, with liners fitted between the straps in wake of frames.

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Doubling plates are fitted in wake of hawse pipes and anchor beds, in wake of all holes for sea chests, etc., forward, for chafe of anchor chains, and aft in vicinity of sternposts.

Inner bottom.—The inner bottom of a battleship is generally of 15 lb. plate below the watertight longitudinal, and 10 lbs. above.

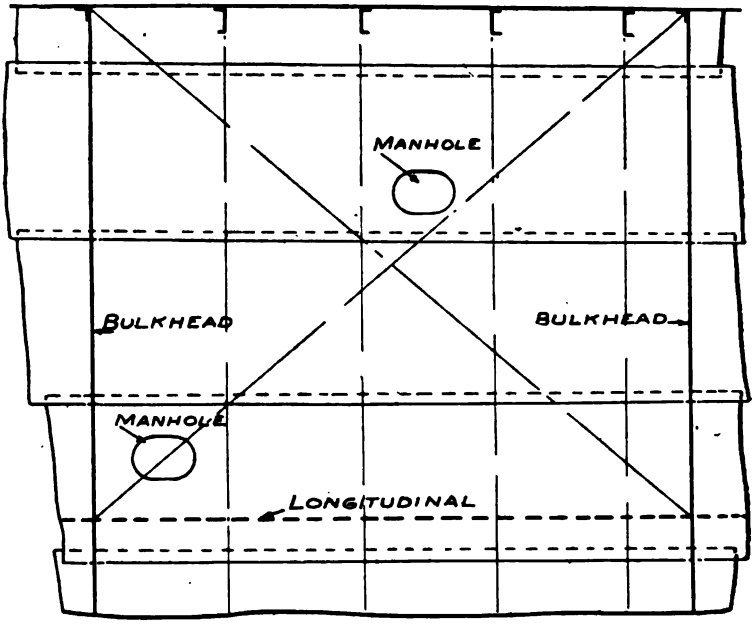

FIG. 113.—INNER BOTTOM COMPARTMENT.

The middle plate or keelson plate is 15 lbs. also. In our earlier battleships, up to and including the *Maine* class, this inner bottom extended to the 5th longitudinal, and was then continued up to the protective deck by a vertical bulkhead called the *wing* bulkhead. In our later battleships, the inner bottom has been made continuous to protective deck.

It is important to have convenient access to all parts of the inner bottom space, for inspection, cleaning, etc. It would be best to have two manholes at opposite corners of the inner bottom compartment, but owing to obstructions overhead, this is generally not possible.

A sketch of an actual arrangement is shown (Fig. 113).

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Manholes, as fitted in the U. S. Service, are one of two standard types—low coaming or high coaming—as shown in sketches (Fig. 114).

At some other places, as on cofferdams and bulkheads, where occasional access through is necessary, the edge of the hole is fitted with a ring and stud bolts, and a portable plate is secured by nuts on these studs (see Fig. 115).

All inner bottom spaces are tested under water pressure, in building, to a head of 35 feet above bottom of keel, and if the test is not satisfactory, the defects have to be made good and the compartments retested.

For vessels of the armored cruiser type, the plating is nearly identical with that for battleships, both in thickness and arrangement, and therefore no special treatment of the subject is given here.

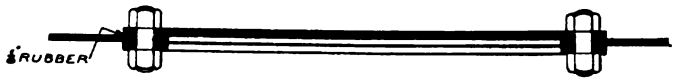

FIG. 115.—PORTABLE PLATE.

Outer bottom and inner bottom of large cruisers of *Columbia* type (400′ × 58′ × 7400 tons):

This plating is arranged on same principle as for a battleship, but the thickness is generally somewhat less, the outer flat keel plates being 25 lbs., inner keel plate 22½ lbs., reduced to 20 lbs. at ends, and the remaining strakes of shell 22½ lbs.

The inner bottom plating is 12½ lbs. The distribution of inner bottom plating presents no special features, extending in this type of ship to the watertight longitudinal on either side (No. 4), the watertightness being continued thence to protective deck by vertical bulkheads, and the coal being stowed against the shell, and three skins between the water and boiler rooms, obtained by the shell plating, the outer coal-bunker bulkhead, and the inner coal-bunker bulkhead.

A sketch cross-section and a plan in outline showing watertight subdivision are indicated in Fig. 116, the sketch being for a modern armored cruiser.

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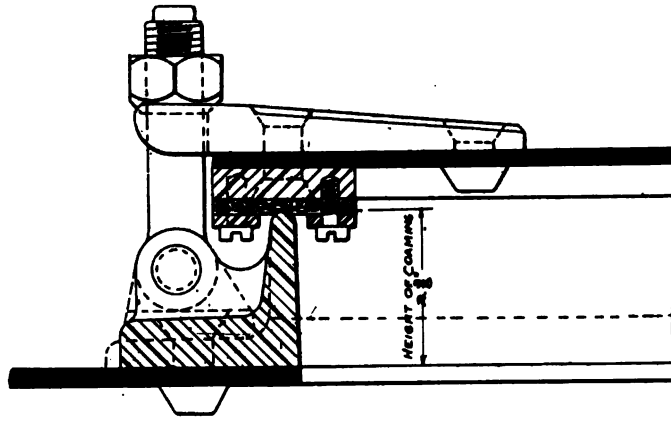
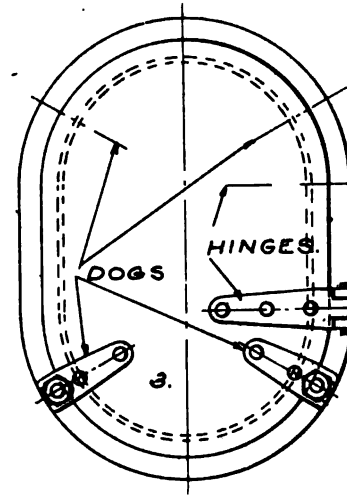


1. Low Coaming Manhole.



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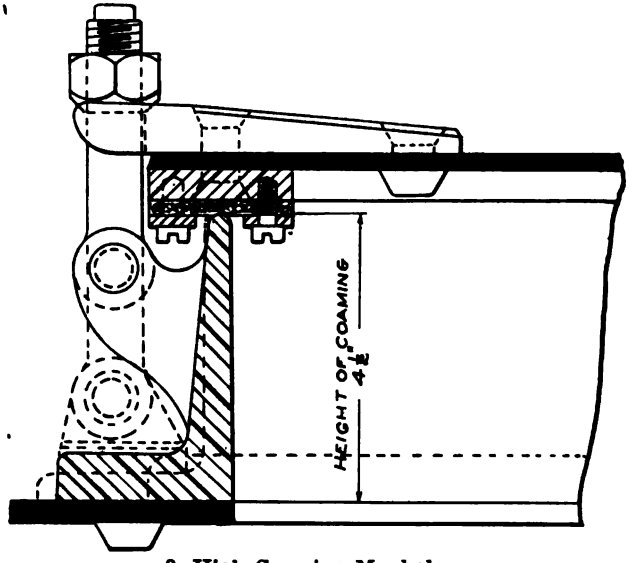

2. High Coaming Manhole.

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Plating of a scout (420′ × 46′ 8″ × 3750 tons).—In general, this plating is 15 lbs., reduced to 12 lbs. at ends. Inner flat keel

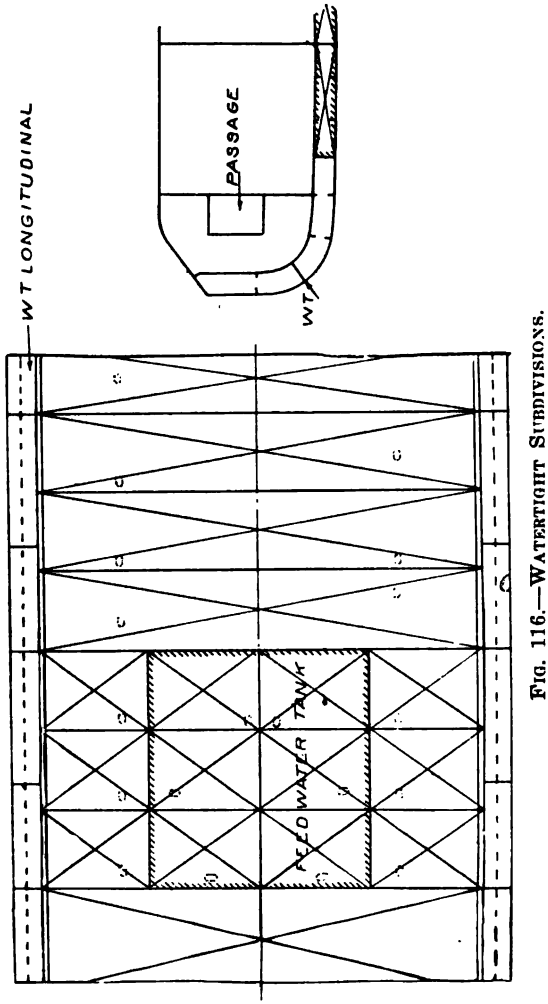

FIG. 116.—WATERTIGHT SUBDIVISIONS.

plate is 17½ lbs., and the outer plate is 20 lbs. Inner bottom plating is 10 lbs., except center strake, which is 15 lbs., and 33 inches wide.

Plating of a cruiser of the Denver type (292′ × 44′ × 3200

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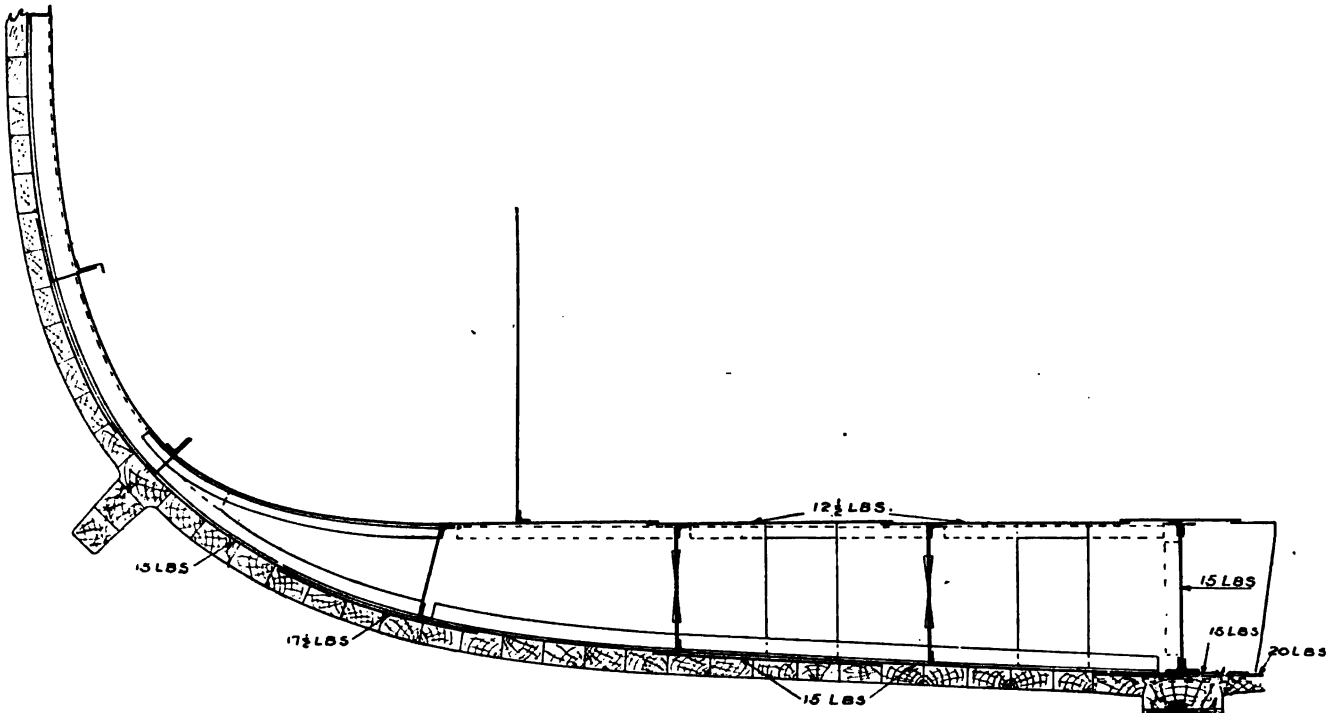

FIG. 117.—SECTION OF U. S. S. DENVER.

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tons).—The outer bottom plating is 15 lbs., including inner flat keel, the outer flat keel being 20 lbs., and the sheer strake doubled, of 15 lbs., with double-riveted straps at butts of each thickness. The *Denver* is a sheathed cruiser, being covered with planking in a manner which will be described later. The inner bottom is carried out to a margin plate or longitudinal just below the turn of bilge, the top of the inner bottom being kept level and the construction resembling somewhat that in the merchant service. The weight of inner bottom plating is 12½ lbs. near middle of length, and 10 lbs. at ends (Fig. 117).

Outer and inner bottom plating of Dubuque class.—These ships, being composite, have no continuous outer bottom plating; it is worked under tanks, shaft alleys, longitudinals, shaft tube castings, struts, etc. There is a flat keel, in one thickness, of 20 lbs., reduced to 14 lbs. at ends and garboard strakes in wake of magazines and inner bottom (which is under boiler room only) of 10-lb. plate. The garboard strake is connected to the flat keel by single-riveted laps. Above berth deck, the plating is 14 lbs. for about four-fifths of length, and forward and aft is reduced to 12 lbs., except sheer strake, which is 14 lbs. throughout.

Plating of destroyer (245′ × 23′ × 420 tons).—For this type of vessel, special high-tensile steel is used. There is no inner bottom. The flat keel is 12½ lbs., in one thickness, reduced at ends to 10 lbs. Sheer strake is 12½ lbs., reduced to 10 lbs. at ends, and of nickel-steel. All plating below the water-line is galvanized. Shell plating, in general, is 9 lbs., reduced to 7 lbs. at ends, except garboard, which is 10 lbs., reduced to 8.

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CHAPTER XIV.

WATERTIGHT SUBDIVISION, BULKHEADS, DOORS, ETC.

Rules for Numbering Compartments of Vessels of the United States Navy.

SEE FIG. 118.

A, *B*, *C*, *D*—Four principal divisions of ship.
X—Forward transverse bulkhead of forward boiler compartment.
Y—After transverse bulkhead of after boiler compartment.
Z—After transverse bulkhead of after engine compartment.
P—Inner bottom.
Q—Protective, armored, or watertight deck.
R—Deck at top of armor belt.
S—Spar or main deck.

Division *A* is from stem to *X*
" *B* " " *X* " *Y*
" *C* " " *Y* " *Z*
" *D* " " *Z* " stern.

Extending from keel to spar or main deck in the line of the bulkheads *X*, *Y*, *Z*, or these bulkheads prolonged when the bulkheads do not extend to the spar or main deck, the spaces between decks that extend through two of the principal divisions will be numbered as if situated in the forward division, and will have that number only.

1. Compartments above the armored, protective, or watertight deck to be numbered, beginning with 100 and upwards.

2. Compartments above the inner bottom, but below the armored, protective, or watertight deck, to be numbered, beginning with 1 and upwards.

3. Compartments in the inner bottom to be numbered, beginning with 99 and numbering downwards, commencing aft.

4. Compartments in each division to be numbered consecutively from forward to aft, except in inner bottom, which is the reverse.

5. Compartments on starboard side to have odd numbers; those on port side to have even numbers.

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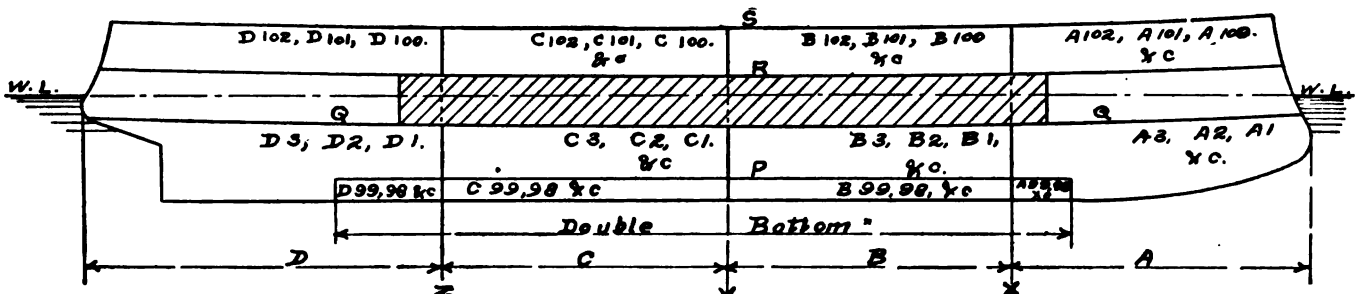

FIG. 118.

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6. Magazines, shell rooms, etc., where explosives are stored, to have the letter *M* after the number of the compartment, as *A. 5-M.*

7. The number of the compartment will always be prefixed with the letter indicating the principal division of the ship in which the compartment is located, as *A. 100, B. 3, C. 99,* etc.

8. If there are two fire-rooms, the forward one must be marked *B. 1,* and the after one *B. 2;* should they be abreast each other, the one on the starboard side must be marked *B. 1,* and that on the port side *B. 2.*

9. If more than two fire-rooms, they will be numbered in similar manner. The same arrangement applies to the engine-rooms also.

Numbers *100,* or above, indicate compartments above the armored, protective, or watertight decks.

Numbers *99,* and under, indicate compartments in the inner bottom.

Numbers *1,* or above, indicate compartments above the inner bottom and below the armored, protective, or watertight deck.

After numbering all the compartments immediately above the inner bottom, those above the platform deck will be numbered in a similar manner, the numbers extending consecutively; the same applies to the decks above the protective or watertight deck.

Valves and Watertight Doors.

1. Sluice and manifold valves of the drainage system, to be numbered and marked with the number of the compartments they drain and connect. All valves to be marked with an arrow showing direction for turning handle to open them, and an index to show whether they are open or closed.

2. Watertight doors are to be numbered consecutively from forward to aft, with numbers distinctly marked on them.

3. There will be prepared for all vessels under construction the following tabular lists for issue to the ships:

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LIST OF COMPARTMENTS.

Number of Compartment.	Location.	Extends Between Frames.

LIST OF ALL VALVES OF DRAINAGE SYSTEM.

No. of Valve.	No. of Compartment in which Valve is located.	Whether Valve can be worked from upper deck.	No. of Compartment or Compartments which it drains.

LIST OF WATERTIGHT DOORS.

Number of Door.	Number of Compartments it connects.	Whether it can be worked from upper deck.

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The main methods of obtaining watertight subdivision in a warship are:

(1) Watertight inner bottom with watertight longitudinals and floors.

(2) Watertight decks and flats.

(3) Transverse bulkheads, watertight.

(4) Longitudinal bulkheads, watertight.

(1) and (2) have been dealt with, and we have seen that in certain types of ships the valuable feature of an inner bottom has to be dispensed with, owing to the cost in weight and space. In all warships, however, at least three of the four means above are used.

This chapter is to deal with bulkheads, which, in addition to dividing the ship into watertight compartments, form a considerable part of the ship's structural strength.

Transverse bulkheads.—Figs. 119 and 120 show in outline the number and location of such bulkheads in the types of ships which they represent. The bulkhead nearest the stem, and extending to berth deck, is the *collision* bulkhead. Instances are not wanting, in merchant ships, where, after collision, this bulkhead has remained intact and saved the ship. No openings are fitted in it.

The type of construction of any bulkhead is determined by the area and depth of unsupported plating likely to be exposed to water pressure. All bulkheads in U. S. ships are tested during building to the water pressure which they are apt to be called upon to withstand in service, by actually filling the compartment which they bound, to the required height. Main longitudinal bulkheads, such as centerline bulkheads and coal-bunker bulkheads, are continuous, the transverse bulkheads being intercostal between them, but, except in particular cases, continuous from inner bottom to protective deck. Forward and abaft the machinery spaces, the transverse bulkheads are well supported by decks and flats and the stiffening required by them is relatively small. Such bulkheads, except where they form supports for turret structures and require special stiffening in order to act as struts, are usually formed of a lower strake next the inner bottom, of 14 lbs., next strake 12 lbs., and remaining strakes 10 lbs., strakes being worked

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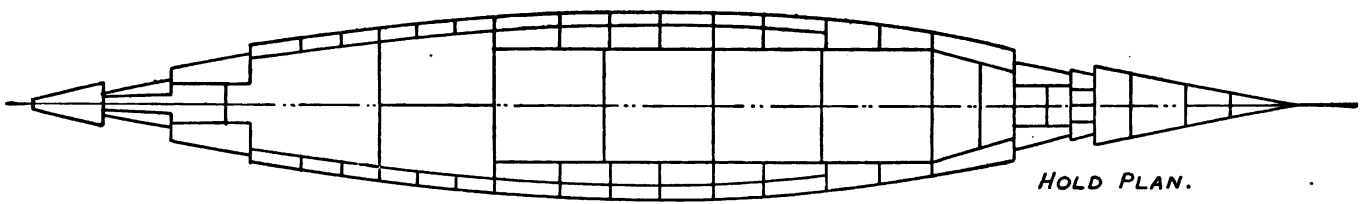

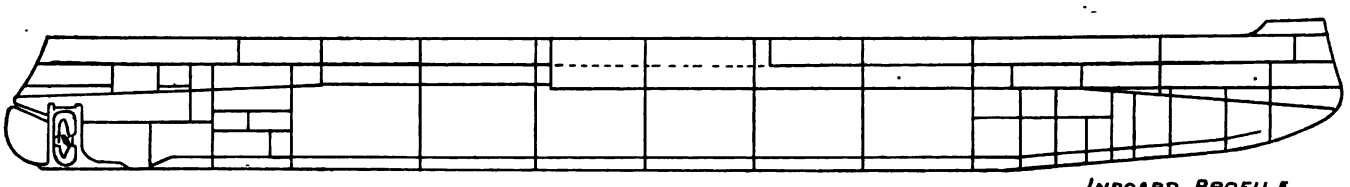

FIG. 119.—"COLUMBIA."

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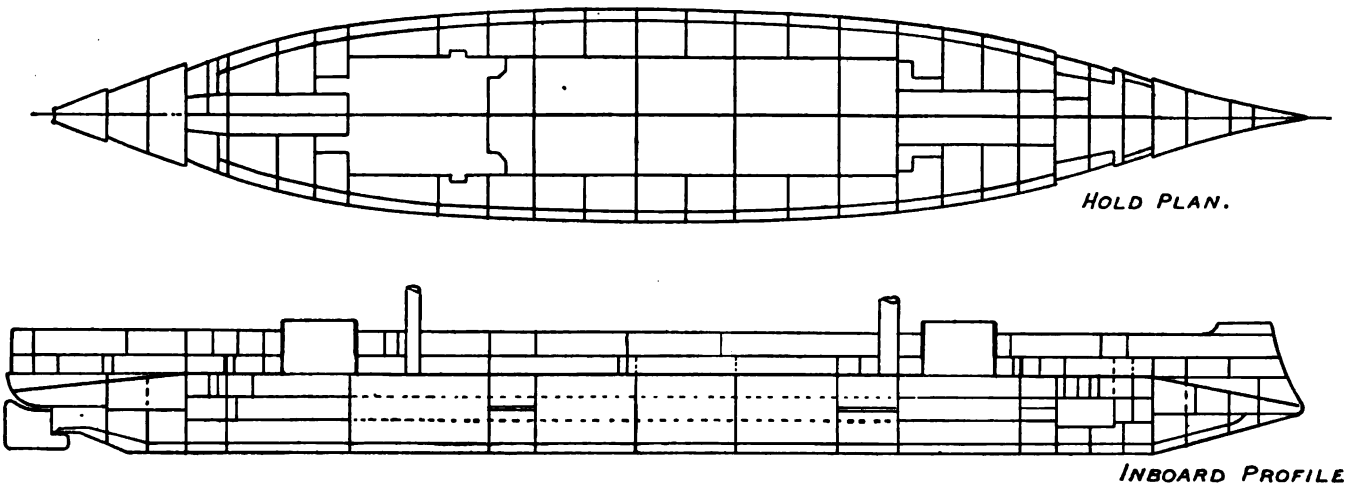

FIG. 120.—"CONNECTICUT."

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horizontally clinker fashion, except where double stiffeners are worked, and then on the raised and sunken system. The stiffeners are of channels 6″ × 3½″ × 3½″, spaced 3 feet, bracketed at heads and heels by flanged brackets 24″ × 18″ of 15-lb. plates. (Fig. 121.)

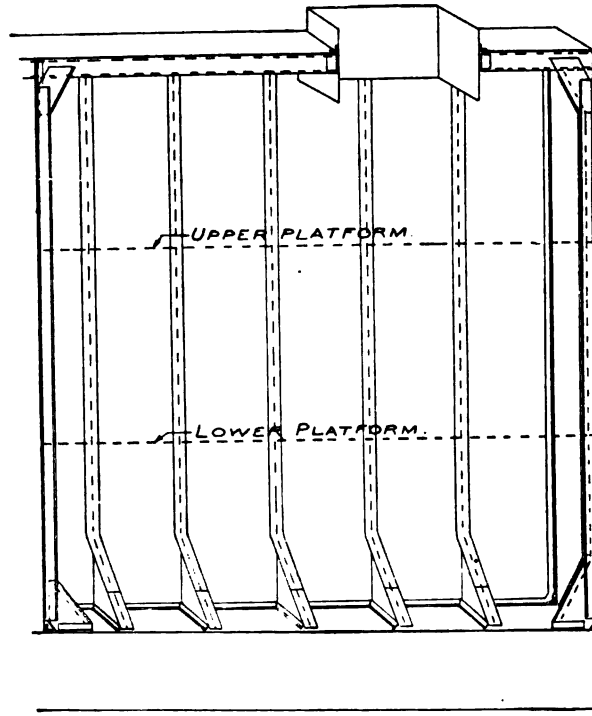

FIG. 121.—BULKHEAD STIFFENERS.

Turret support bulkheads are built of 15-lb. plating, with stiffeners and brackets as described above, and such extra stiffening as is required to suit their special purposes.

The transverse bulkheads separating engine and boiler rooms, and the other main transverse bulkheads, consist of the two lower strakes of 14 lbs., next strake 12 lbs., and remaining strakes 10 lbs. The stiffeners are of 6″ × 3½″ × 3½″ channels, with 15-lb. bracket 36 inches deep at bottom and 15-lb. brackets 30 inches

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deep at top. The stiffener is reinforced on inner edge by 3″ × 3″ angle and a 20-lb. face plate. Stiffeners are spaced 4 feet, and worked on both sides of bulkhead where bulkhead has no support from flats; elsewhere on one side only.

Transverse bulkheads in way of inner bottom are bounded thereby, and the watertightness is continued to inner bottom by watertight frames.

Intermediate between main transverse bulkheads, transverse divisional bulkheads are fitted in bunkers, as shown on hold plans in Figs. 119 and 120.

FIG. 122.
VERTICAL KEEL STAPLING.

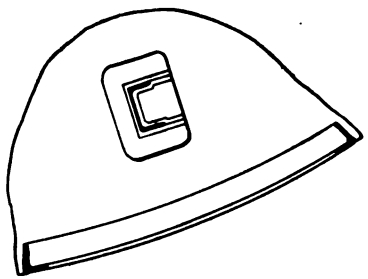

FIG. 123.
"LONGITUDINAL" STAPLING.

Fore and aft longitudinals, vertical keel, etc., are worked continuous through all transverse bulkheads, watertightness being secured where the type of longitudinal is that forward and abaft inner bottom, with collars. (Fig. 122, 123.)

A number of transverse bulkheads are carried watertight up to gun deck, which is an important point in view of sinkage, heel and change of trim that might ensue after damage.

All the watertight bulkheads are stopped at a watertight flat or carried well above water, to insure, as far as possible, confining water which may enter on one side of them.

Longitudinal bulkheads.—There are a number of small longitudinal bulkheads forming boundaries of magazines; these assist

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in maintaining watertight subdivision, but, as they are of small area, are of 10-lb. plate, stiffened by 4″ × 3″ angles, spaced 2 feet, with angle clips at top and bottom.

The principal fore and aft bulkheads in a large ship are:

(1) Centerline bulkhead in engine room, and, in most U. S. ships up to present day, in boiler room.

(2) Inner coal-bunker bulkhead.

(3) Outer coal-bunker or wing bulkhead.

(4) Upper coal-bunker bulkhead.

All these except (4) are shown in Figs. 119 and 120; (4) is generally directly above (2) and between protective and gun decks.

Centerline bulkhead.—This bulkhead extends, in most of our battleships, from the after end of engine room to the forward end of boiler room. In future designs this will probably be omitted in boiler rooms. It is watertight from inner bottom to protective deck. Provision must be made to prevent water running over the top in case one engine room is flooded, by carrying this bulkhead up to the gun deck if necessary, or by fitting watertight hatches in the protective deck. It is essential that this bulkhead be amply strong; it is of 14 lbs. for the two lower strakes, 12 lbs. next, remainder of 10 lbs. Stiffeners spaced 4 feet, of 6″ × 3½″ × 3½″ channels on each side, reinforced on inner edge by 3″ × 3″ angle and 20-lb. face plate, in manner similar to main transverse bulkheads. Plating is on raised and sunken system, with parallel liners. Butts of plates are lapped and double-riveted.

Inner coal bunker bulkhead.—This being supported by divisional bulkheads in coal bunkers is plated as above, except that it is built on the clinker system, with double-riveted laps and butts, and stiffeners on one side, of type as specified for centerline bulkhead above.

Outer coal-bunker or wing bulkhead.—This bulkhead, when fitted, forms a vertical continuation of the inner bottom, is plated the same as the inner coal-bunker bulkhead, and generally stiffened in the same way as the inner bulkhead.

Upper coal-bunker bulkhead.—This being only worked from protective to gun deck, will not be called upon to stand much

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pressure; it is of 10-lb. plate, stiffened by 4″ × 3″ angles spaced 2 feet. Other structural bulkheads above protective deck are built in this way.

The beams of a ship run continuously through longitudinal bulkheads, and in order to make the upper part of such bulkheads watertight, angle bars are smithed to fit the space between beams. The riveting is close-spaced and the staples carefully calked. (Fig. 124.)

Bulkheads under barbettes and turret foundations are specially stiffened with additional 6″ × 3½″ × 3½″ channels, as necessary, to assist in supporting the weight and shock of gun fire.

Above gun deck, the bulkheads are only made watertight to 12 inches above deck.

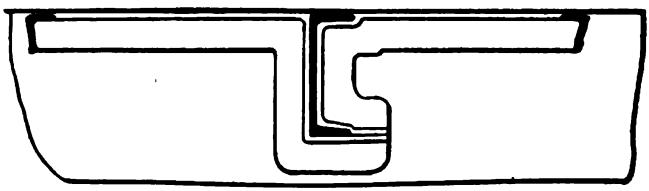

FIG. 124.—BEAM STAPLING.

Numbering of bulkheads.—Transverse bulkheads are distinguished by the number of the frame on which they are located. Longitudinal bulkheads are distinguished by name and also by numbers of frames between which they extend, as *centerline bulkhead, inner longitudinal coal-bunker bulkhead, bulkheads 68 to 79, etc.*

Water testing.—All watertight decks, flats, and bulkheads, and the outer bottom, inner bottom, and watertight floors are tested for watertightness under pressure. The following quotation as to watertight testing is made from specifications of a typical recent battleship, as indicating the requirements:

"All watertight compartments below the berth deck, including one of the engine or boiler rooms, ... are to be tested by filling the compartments with water under a head. The boiler or engine compartment mentioned above; also a typical structural

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bulkhead of each variety in the ship below the berth deck, except partition bulkheads in magazine spaces; the forward and after trimming tanks; the next compartment in the hold adjacent to these tanks; also all double-bottom compartments to be utilized as feed-water tanks, and a type compartment of the double bottom, will be tested under a head of 35 feet above bottom of keel. Care will be taken in making these tests that the doors in the partition bulkheads in magazine spaces are left open, or other means provided to relieve them of the 35-foot pressure on adjacent bulkheads. These partition bulkheads will be tested to a head of water 5 feet above their tops. All other compartments below berth deck will be tested under a head of water equivalent to the height of the berth deck amidships. All cofferdams to be tested under a head of 2 feet above the top of the cofferdams. Docking keels will be tested to a head of 35 feet. Shaft tubes will be tested to 30-lbs. pressure per square inch. All compartments adjacent to the outside plating must be tested before launching, and in all cases the testing must be done before the compartment is painted or cemented, and with permanent doors, manholes, and hatches fitted in place. . . . Any leaks which develop must be corrected, and where same occur by the first test, the compartment will be refilled under the specified head and the testing continued until watertightness is secured. Bulkheads and flats subjected to the head of 35 feet must stand the pressure without appreciable permanent set, or deflection sufficient to cause serious leakage or to approach collapse. The trimming tanks, the hold compartments adjacent to same, and feed-water tanks, must be absolutely tight under the pressure. Members tested under a head equivalent to the height of the berth deck must be able to stand the pressure without permanent set or leakage. The same degree of watertightness must be obtained for doors, hatches, etc., as for structural parts in the immediate vicinity.

"Any deficiencies in stiffening which may be made apparent by the above tests are to be made good.

"Watertightness will, in all cases where practicable, be secured by metal calking, the use of stopwaters to be limited to a minimum. . . . . Stopwaters when used between plates, or between plates

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and angles, should be tarred hemp felt or flat lampwick soaked in a mixture of red and white lead, or, where the same can be properly applied, a stiff mixture of red and white lead putty. Grommets should be of lampwick soaked in red and white lead.

"Watertight members above the berth deck will be tested by playing a hose on them."

A large number of holes are necesssary in bulkheads for the purpose of connecting fittings to the bulkheads. It is important to note that the screws, etc., used for such attachments are watertight, and that if any are removed, the hole is suitably closed.

Glands and stuffing boxes are fitted for passage of all pipes, wire, etc., through watertight bulkheads, and should be examined periodically to see if in proper condition.

The large openings in watertight bulkheads necessary for access from compartment to compartment, are fitted with suitable watertight doors. These in the U. S. Service are of various sizes to suit the particular location for which desired. They are of three general types:

(1) Hinged watertight doors.

(2) Vertical sliding doors.

(3) Horizontal sliding doors.

Type (1) is always operated by hand. Types (2) and (3) are operated, (a) by hand only, (b) by hand and by power, which may be hydraulic, pneumatic, or, as in the latest type, electric.

Each of these types of doors differs in details in different classes of vessels owing to improvements and minor variations in practice of the building yards. They are, however, described in principle in Barton's Naval Engines, page 275, *et seq.*, to which the student is referred. Models are on view in the model room.

Automatic ventilation valves.—As will be explained in the Chapter on Ventilation, the earlier types of ventilation systems required certain automatic valves at watertight bulkheads to preserve the watertightness. These are not now fitted, but the operation of those that have been fitted is explained in the Chapter on Ventilation.

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CHAPTER XV.

STEMS, STERNPOSTS, RUDDERS, AND SHAFT STRUTS.

Stems.—The simplest form of stem is made of a flat bar to which the plating at forward end of ship is secured. This form is generally used in the merchant service and in the smaller cruisers, gunboats, and destroyers in the U. S. Service. For larger warships it has been customary in the past to provide a heavier form of stem, securely backed up to form a ram, so that the vessel may ram another without suffering severe damage herself.

The present tendency is to break away from this form of stem, as it complicates the handling of anchors, and is not the best form for sea purposes, and seagoing officers at present doubt the practicability of ramming in action.

The usual and most effective form of stem for ramming is one having a ram below water, projecting forward so that it shall damage the unarmored under-water portions of the structure of the enemy's ship and project well inside the enemy before being brought up by the stronger structure above.

Stems of this character in the U. S. Service are made of cast steel. It is customary, on account of the complicated form and great weight, to make these stem castings in two pieces, the two being connected together about the level of the berth deck by a suitable scarf. This is sometimes made a table scarf, and at other times a side scarf. Fig. 125 shows the construction of such a stem.

Assuming the ram to be fitted, it is essential to provide suitable support by the adjacent structure. The following provision is made for this:

(1) The outer bottom plating is doubled in thickness and rabbetted (*i. e.*, recessed) into the casting.

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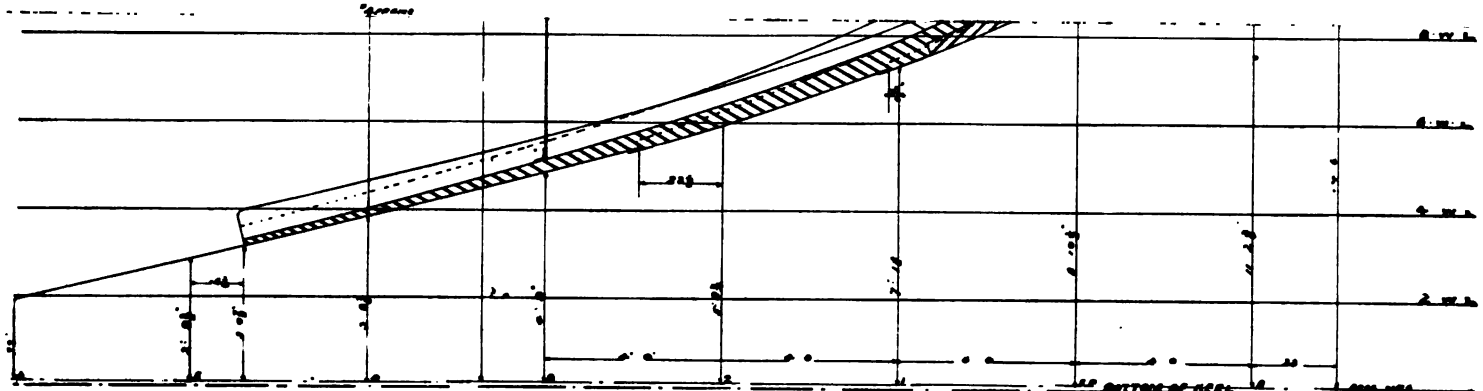

FIG. 125.—STEM.

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(2) The bow protection is rabbetted into the casting for part (sometimes all) its thickness.

(3) The protective deck is well connected to a large projection on inside of stem casting.

(4) A breast hook or horizontal ram plate of 2 to 3 inches is worked, well connected to horizontal web inside ram an extending well back.

(5) The vertical keel runs up to stem and is well connected to vertical web inside ram.

(6) In many ships, additional stiffening plates, called vertical side ram plates, are fitted.

From the above it is seen that great care is taken to suitably support the stem, both against the direct shock, and also, by (3) and (4), against the bending action brought into play when the ships swing after impact.

In the *Denver* class, to prevent corrosion from galvanic action between copper sheathing and steel, a bronze stem is fitted, Manganese bronze is employed for this purpose on account of its physical qualities.

Sternposts.—In the sheathed ships of the *Denver* class, the sternposts are of bronze, as are the stems.

The sternpost of a single-screw or triple-screw ship has to be formed to receive the propeller and also to form a support on which to hang the rudder.

Nearly all vessels now in the U. S. Service are twin-screw, so that the function of the sternpost, in addition to receiving the after end of the plating, is to receive the rudder.

The shapes of sterns of ships vary considerably in different classes, but in all warships a condition essential to the safety of the ship is to be fulfilled, *i. e.*, that the stern be so formed that rudder and steering gear will be well below water and under suitable protection. The stern is therefore carried well abaft the rudder-head to accomplish this purpose.

In U. S. battleships the sternpost is a casting, with projections on which the rudder can be supported. Fig. 126 shows a typical sternpost for a recent battleship, and for our armored cruisers it is not essentially different.

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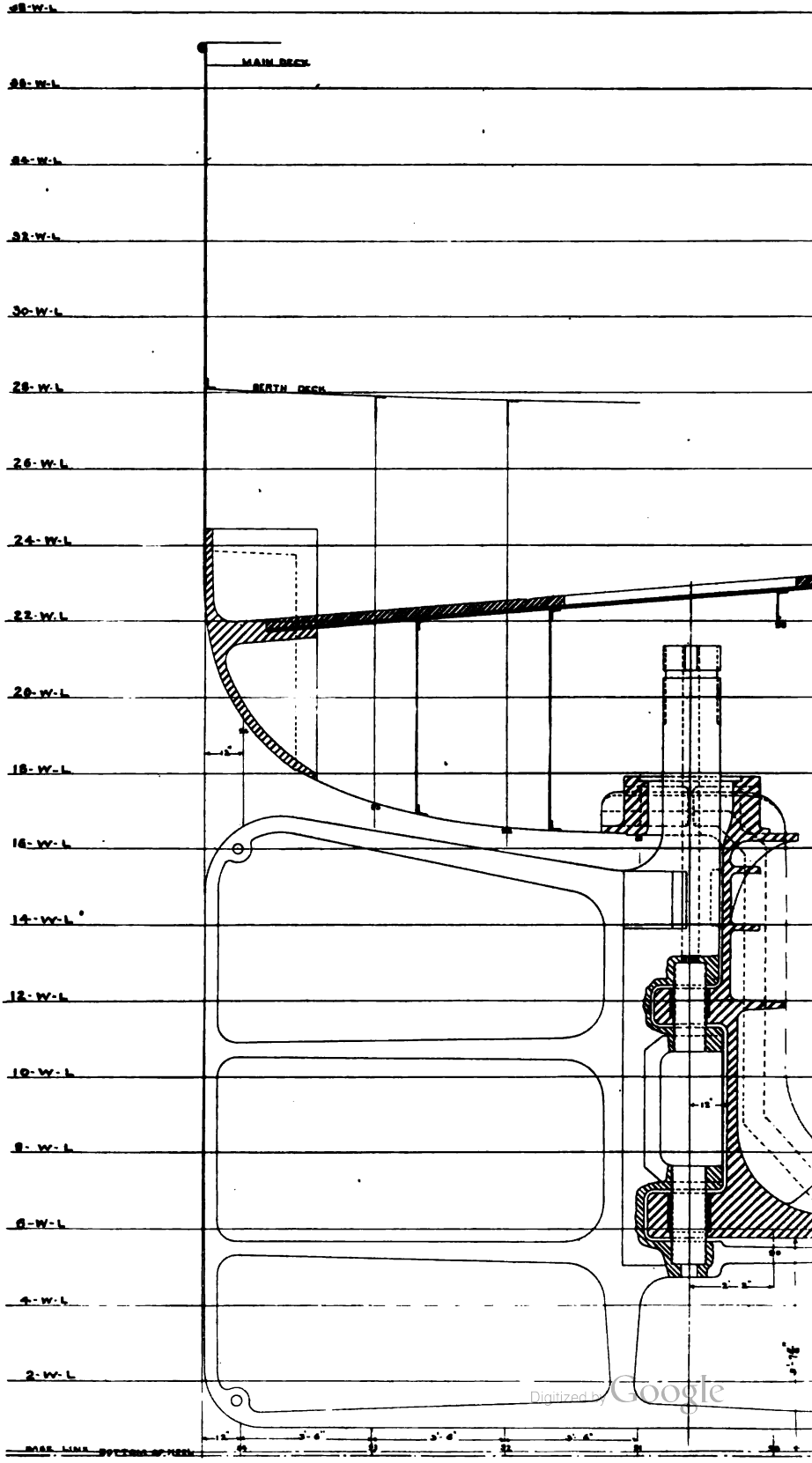

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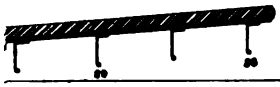
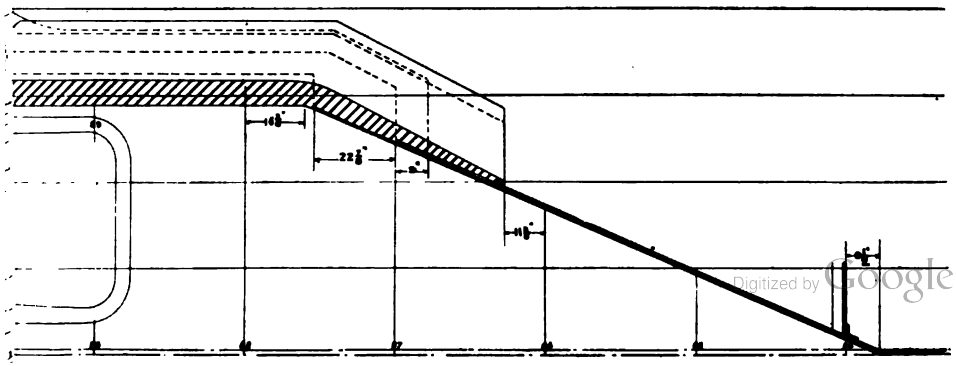
Fig. 126.

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It is customary to take the weight of the rudder at the top of the sternpost casting, which has to be made specially strong on this account. Intermediate or steadying pintles are provided below.

Rudders.—It should be noted that rudders of the more recent battleships and armored cruisers and large twin-screw ships are of the *balanced* type, while for the *Minneapolis, Denver,* and smaller ships they are of the *unbalanced type.* (See Fig. 127.)

Up to within recent years, rudders have been of nearly rectangular shape, hinged on the fore side, and unbalanced. Rudders of this type were fitted in our earlier steel cruisers and our earlier battleships. The weight in this type of rudder is taken at the head, as later explained in the case of balanced rudders. The sternpost projections, including the one at the bottom in which pintles are fitted, simply fix the points against bending and act as bearings in rotating.

The frame of the modern rudder, whether balanced or not, is cast steel, lightened out as much as possible, and in way of the axis necessarily of massive construction to stand the large twisting moment. The sides are covered with 15-lb. plates, and the space inside filled with white pine.

The rudders of the more recent ships are all balanced, *i. e.,* a portion of the area is fitted forward of the axis, which renders the steering easier, as the center of pressure is brought nearer the axis.

If we test a rectangular plate by towing it through the water, inclined at an angle of 30° to 40° to line of advance, it is found that the center of pressure is about one-third the breadth from leading edge. Therefore, to balance a rudder, considerably less than half the total area should be before the axis. Generally from 12% to 20% of the total area.

With a balanced rudder the twisting moment is small, and less power is needed in the steering gear than with the unbalanced type.

The pressure per square foot of rudder area increases as *square of speed,* so that comparing 22 and 18 knots, the proportion of pressure for equal areas is $\frac{484}{324} = 1.5$, *i. e.,* an increase of 50 per cent.

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From this it would appear that if in an armored cruiser of 22 knots, an unbalanced rudder were fitted, the steering gear would

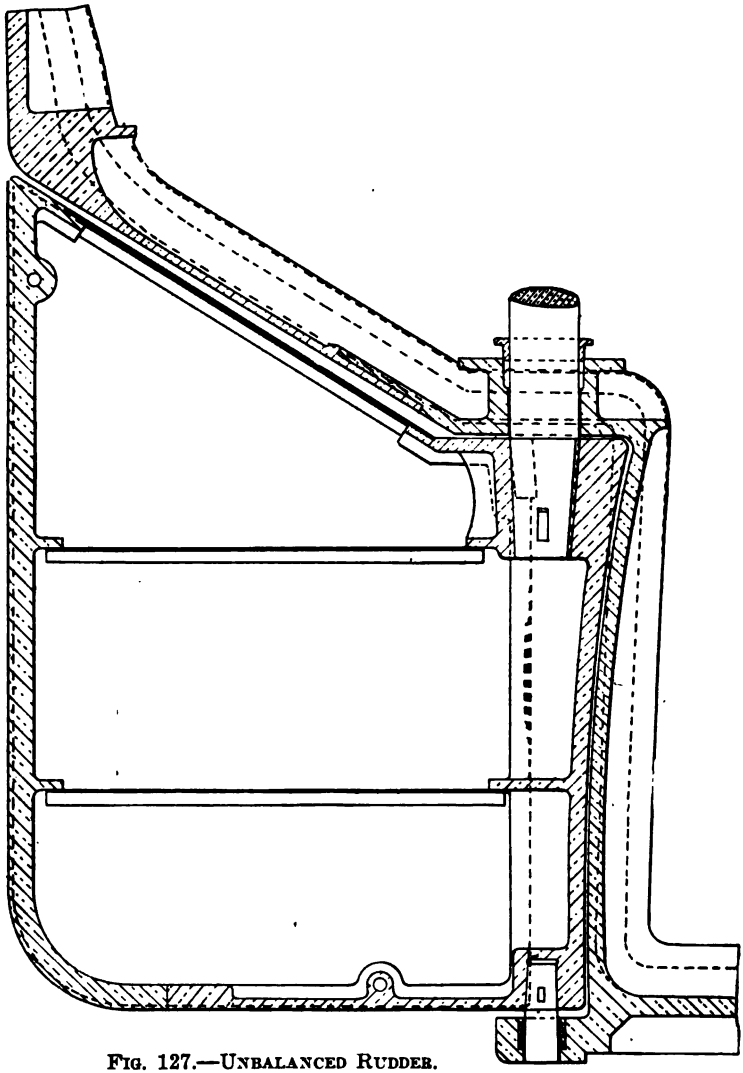

FIG. 127.—UNBALANCED RUDDER.

be much more massive than in a battleship, and steering by hand would be practically impossible.

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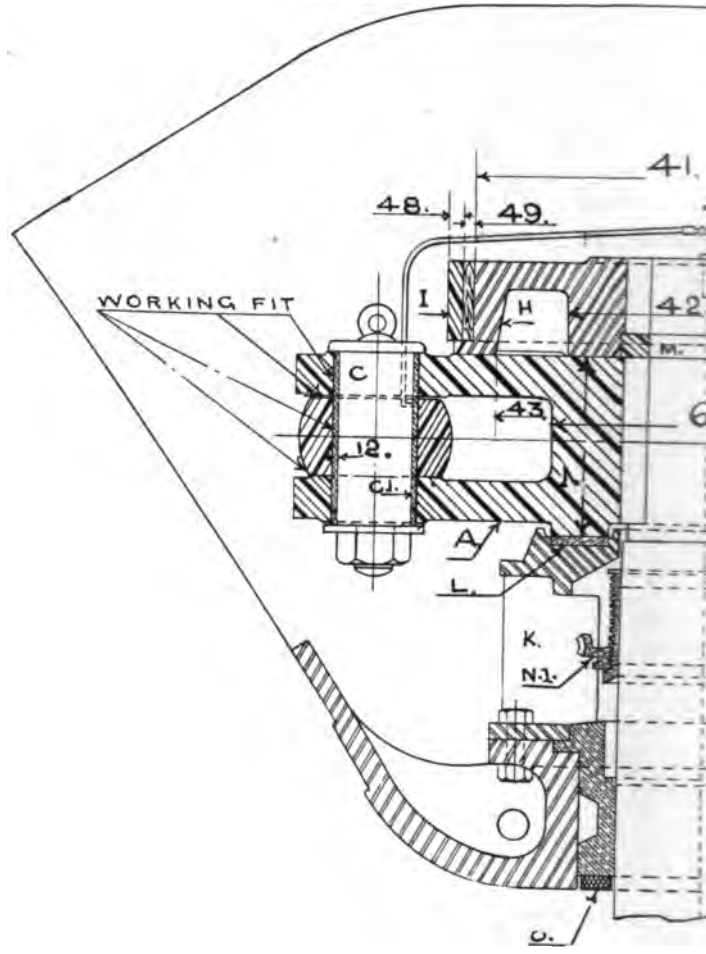

SCALE

FIG. 128.—FITTINGS AT

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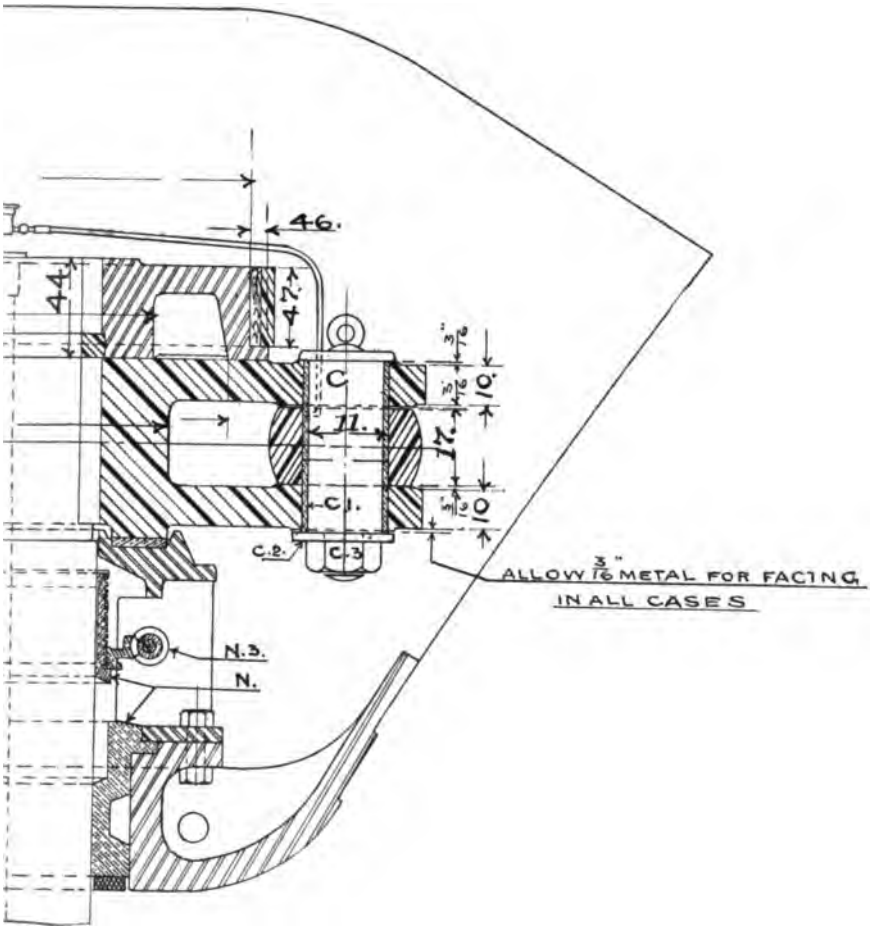

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HEAD OF RUDDER STOCK.

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The weight of the rudder is taken at the top of rudder-stock by the sternpost.

From (Fig. 128) it will be seen how the weight is taken. At the top of the sternpost a recess is formed, and in this is fitted a bearing ring, in halves, encircling the rudder-stock. The rudder crosshead is fitted on over the stock, and keyed for twisting by two rectangular keys at 180° from each other. The bottom of this crosshead slides on a circular metal bearing attached to the sternpost, and the weight of the rudder is taken by an annular key or ring, fitting into a recess at the upper end of the stock. Above this is fitted a circular piece of metal, also keyed to the rudder-stock, on which is fitted a band brake for locking the rudder when the steering gear is broken.

For high speeds, with balanced rudders fitted, the *bending* is of importance as well as the *twisting*. This is indicated by sketch (Fig. 129), the rudder being held at one end and supported at the pintles. It is evident that in either case a considerable force has to be taken by the lower pintle, and a large bending moment at the rudder head. In designing, the condition going astern should be investigated, as this may be the worst case.

The twisting moment combined with the bending moment will determine the necessary size of rudder-stock.

In any warship rudder, as the head is under water, the hole in the stern has to be made watertight. The construction of this work, its stuffing-box and gland, is shown in Fig. 128.

Projections are cast on the rudder to bring up on the sternpost when the rudder is hard over, thus limiting the angles to which the rudder may be put; these are generally at 35° either side of longitudinal center line.

Shaft struts.—In twin-screw vessels, a considerable length of the propeller shafting is outside the ship, and struts are fitted on each side immediately forward of the propellers, to take the weight of the propellers, after end of shafting, etc. For steel ships, these struts are of cast steel; in the sheathed ships of the *Denver* class, of manganese bronze. These struts do not have to take any of the fore and aft thrust, which is taken in the engine room by

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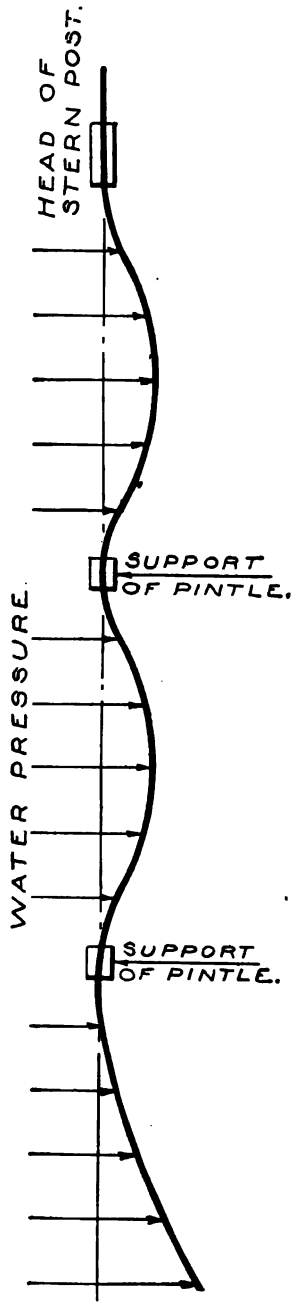

FIG. 129.

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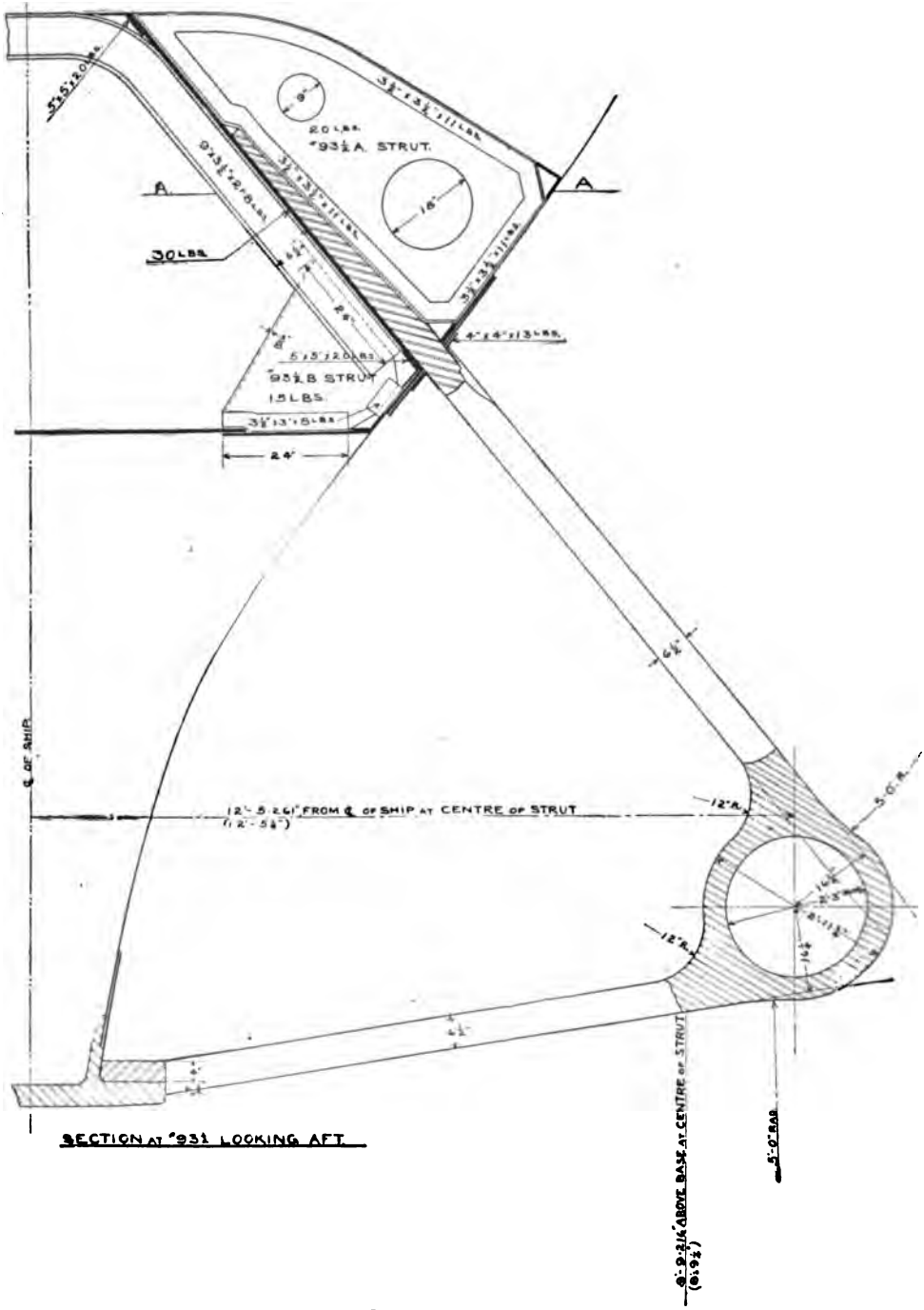

FIG. 130.—STRUT.

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the thrust block, but they have to resist vibration and support a considerable part of the weight, and so the connection requires to be rigid. The arrangement is indicated in Fig. 130.

The arms are flattened out at the top and bottom, the upper palm extends inside the ship, where it is riveted to a heavy fore and aft bracket fitted to receive it. The lower palm is scarphed to fit snugly over a ledge cast on the side of the sternpost proper, at its bottom, to which it is securely fastened by through rivets and tap rivets. The arms of the struts are pear-shaped in section, the blunt end foremost, this being the form of least resistance when fully submerged.

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CHAPTER XVI.

VENTILATION.

The problem of the effective ventilation of a ship is complex and has been the subject of considerable study.

Ventilation is either natural or artificial. *Natural ventilation* means the supply of fresh air and exhaust of foul air without the aid of fans. *Artificial ventilation, i. e.,* ventilation by means of fans, is divided into two kinds: *Supply*—where fresh air is taken from outside and forced into the ship. *Exhaust*—where the foul air inside the ship is drawn out, and the fresh air allowed to come in to replace it in a natural way. Natural ventilation is relied on, solely, only for spaces within the superstructure and deck erections above the main deck. It is relied on to some extent for the spaces between gun and main decks, but not at all below the gun deck, where artificial ventilation is fitted for all compartments requiring change of air. For compartments above gun deck, where artificial ventilation is not fitted, cowls are sometimes fitted, which, when turned toward the wind, conduct fresh air to the space—the exhaust taking place through hatches or other cowls turned against the wind. Air ports fitted in the sides of the vessel are useful for the purpose.

Coal-bunker ventilation.—The ventilation of coal bunkers is important on account of the gas coming from certain kinds of coal. This gas, when mixed with air, forms an explosive mixture and might cause serious damage if allowed to accumulate. The coal-bunkers are ventilated by leading pipes from the coal-bunkers to uptake enclosure. These enclosures are hot and the air in the pipe tends to rise and, for the lower bunkers, fresh air comes in from the boiler room. It is necessary to fit a damper in these pipes to prevent the pressure in the boiler room from being lost when steaming under forced draft.

There are differences in the fittings of different ships, but the general principles may be seen from Figs. 131 and 132.

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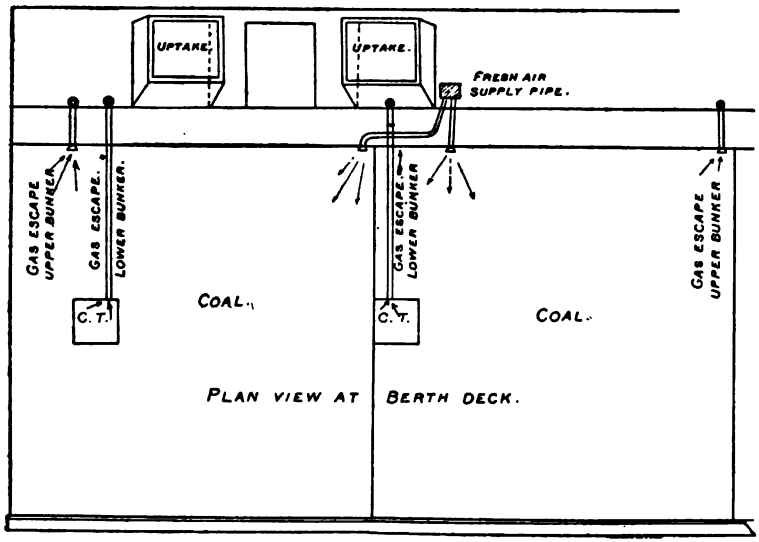

FIG. 131.

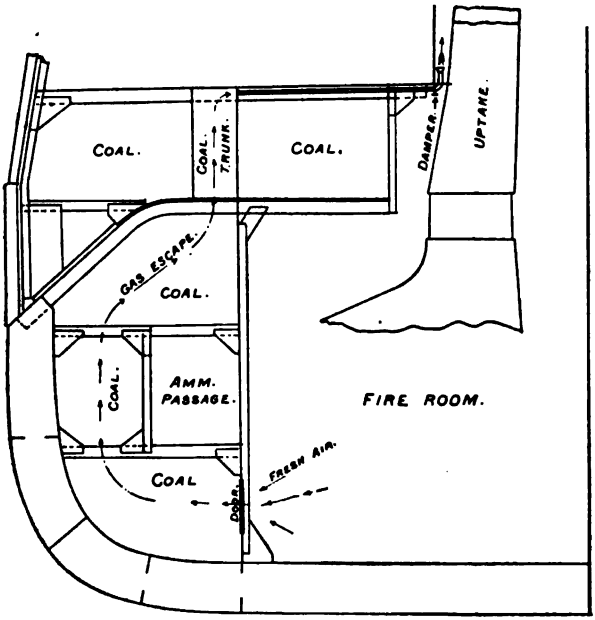

FIG. 132.

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In this ship there are two general division of bunkers:

Upper bunkers.—Above protective deck and behind armor.

Lower bunkers.—Below protective deck and abreast boiler and engine room.

From each upper bunker, a duct of galvanized steel tubing is fitted and led to the uptake. No valves are fitted in these pipes. For each bunker, this pipe is taken from one corner of the bunker, and in the opposite corner, fresh air is introduced through a similar pipe from the adjacent ship's ventilation system.

Lower bunkers.—The exhaust pipes are taken well up under gun deck from the coaling trunks leading from above to the lower bunkers, and led to the uptake casing in the same manner as for upper bunker. No special supply pipe is fitted. Fresh air coming in from the doors into boiler rooms.

Double bottoms.—For confined spaces, such as inner bottoms and unfilled cofferdams, which are closed for long periods, care should be taken not to enter them without first testing to see if the air will sustain life. This is best done by trying a lighted candle in the space for a few minutes. If it will continue to burn, the air will support life.

The manholes to inner bottoms are fitted in pairs and as far apart as possible, and small portable electric blowers used to change the air if desired.

Ordinary ship ventilation.—For ships up to and including the *Alabama* class, this was by groups of large steam-driven fans. A group was located forward, one aft, and one or two amidships, or in this general manner, usually on the upper platform deck, and from these, long ducts of considerable size were led the length of the ship, with louvres and ducts into the various compartments requiring ventilation. This system necessitated piercing many watertight bulkheads, and at these points, automatic valves were fitted to close openings when in contact with water. In the U. S. Service, only two types of these valves were ever much used: The plain ball valve, on which a hollow copper ball floated up when water came into the pipe and seated itself in a seat, forming a watertight joint (see Fig. 133), and the valve designed by the late Naval Constructor Woodward and used first on the *Kearsarge* and

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Kentucky, which, while working very satisfactorily, was complicated and expensive.

This general type of ventilation system has many objections:

(1) The large fans requiring steam engines, with long leads of steam and exhaust pipes, and consequent heating of compartments.

(2) Use of automatic valves to keep flats and bulkheads water-

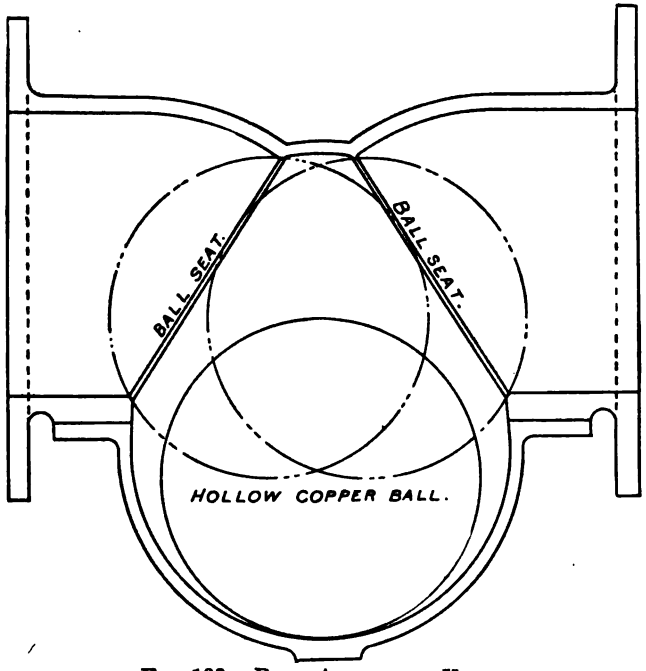

FIG. 133.—BALL AUTOMATIC VALVE.

tight—which seldom worked when needed—destroying the watertight integrity of the various compartments and hence endangering the safety of the ship.

These large steam fans, as usually fitted, were of the reversible type, so that the system could be used as an exhaust or supply as desired, but was generally supply, and when so used, the exhaust was by the regular access hatches, and for some compartments by exhaust trunks.

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The first step away from this system was the substitution of electric for steam-driven blowers, the other features of the system being retained. This was fitted on the *Maine* class.

The present system of ventilation is by a large number of small systems, each system operated by an electric fan. The most recent practice is to make all such systems *supply,* except those for water-closet spaces and operating rooms, where the odors might be forced into adjoining living spaces.

The systems are so arranged that the piping from them does not pierce watertight bulkheads.

The fans are located on the berth deck, or above, and the leads of pipe are vertical, or, if horizontal, confined within the limits of spaces bounded by watertight bulkheads. The vertical piping fitted is watertight to well above the protective deck. This does away with the necessity for automatic valves.

In a recent battleship there are twenty-five of these systems.

The fan draws air from a cowl or trunk carried to the open air above, with a suitable cowl top.

The design and size of piping, the angles of branch leads, etc., has been the subject of considerable experiment to determine the most suitable and efficient form for the work intended.

Ordinarily, exhaust is obtained by hatches and natural openings. Ammunition hoist trunks are utilized where available, and in special cases, as in dynamo rooms, special exhaust trunks are fitted.

The delivery ends of supply pipes are fitted with adjustable metal elbows, so that the air may be directed to any part of the compartment. The ends of all such elbows are covered with wire mesh. Terminals, to prevent whistling, are bell-mouthed to twice the area of the duct, but the velocity of the air through them should not exceed 1000 feet per minute.

Certain spaces, such as magazines, where the temperature is required to be kept low, are fitted with casings worked on the flanges of stiffeners, forming an air space which is connected to the ventilation system. Similar casings are fitted over boiler and engine rooms to prevent excessive heat on berth deck.

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In magazines.—All ducts passing through magazines are watertight. A natural exhaust duct is fitted in each magazine, equal in area to the area of the supply duct, and as far removed from it as possible. This is necessary, as magazines are ordinarily closed airtight, and the ventilation could not continue unless some such provision were made. The upper ends of these exhaust ducts are carried well up under the gun deck, fitted with a goose-neck and covered with wire mesh; the lower ends are bell-mouthed.

Special systems are fitted for ventilating engine rooms and dynamo rooms, being so led as to supply air to the specially hot parts of these rooms.

The following quotation from a recent battleship specification indicates the rate at which the air is required to be changed:

"Officers' quarters and crew space, berth deck, outside of armor bulkheads, in from ten to twelve minutes.

"Officers' quarters and crew space, berth deck, inside of armor bulkheads, in about four minutes.

"Water-closets and crew's head, in about six minutes.

"Storerooms and passages, in eight to twelve minutes.

"Magazines, in from six to eight minutes.

"Engine rooms and steering compartments, in about two minutes.

"Evaporator rooms, in about two and one-half minutes.

"Dynamo rooms, in about three-fourths of a minute."

References to ship ventilation are not many. The best available is an article by Naval Constructor D. W. Taylor, U. S. N., in the Transactions of the Society of Naval Architects and Marine Engineers, 1905, and Specifications of U. S. Ships.

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CHAPTER XVII.

CORROSION, FOULING, AND PAINTING.

Rust.—If iron or steel be exposed unprotected in moist air containing carbon dioxide (CO_2), a chemical action takes place, resulting in the generation of an oxide of iron, called *rust*. This process wears away the iron.

Owing to the CO_2 present in the water, a similar action goes on for iron immersed in water.

The rusting action is much hastened by heat, and where heat and moisture are together, is very rapid.

Corrosion.—Corrosion is much accelerated by galvanic action. Iron and copper in metallic connection, immersed in dilute acid, cause an electric current, and the iron wastes away. Iron and zinc similarly immersed result in the wasting of the zinc.

Sea water is mildly acid, hence the care required in immersing two different metals in metallic connection, to be sure that they are such that the steel of the hull will not be affected.

Iron and its rust so immersed cause the electrolytic action, resulting in the wasting of the iron, from which it is evident that care must be exercised in cleaning the iron.

Rust is hygroscopic, *i. e.*, it takes up moisture, and so dampness gets between it and the iron and hastens the corrosive action.

We have seen, before, the action of mill scale or black oxide formed during manufacture, and the steps taken to remove it prior to working the plates or shapes into the vessel. Mild steel now used in shipbuilding is even more liable to corrosion than iron. A part of the thickness given the members of a ship's structure, particularly in merchant practice, is as margin against corrosion. In warships this is less true, and in such vessels as destroyers, etc., practically no margin against corrosion is allowed, and the greatest care and most frequent examinations are necessary to guard against corrosion. We have seen that the torpedo-boat plating is galvanized as an additional precaution against corrosion.

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From the above it is clear that no part of the structure of a

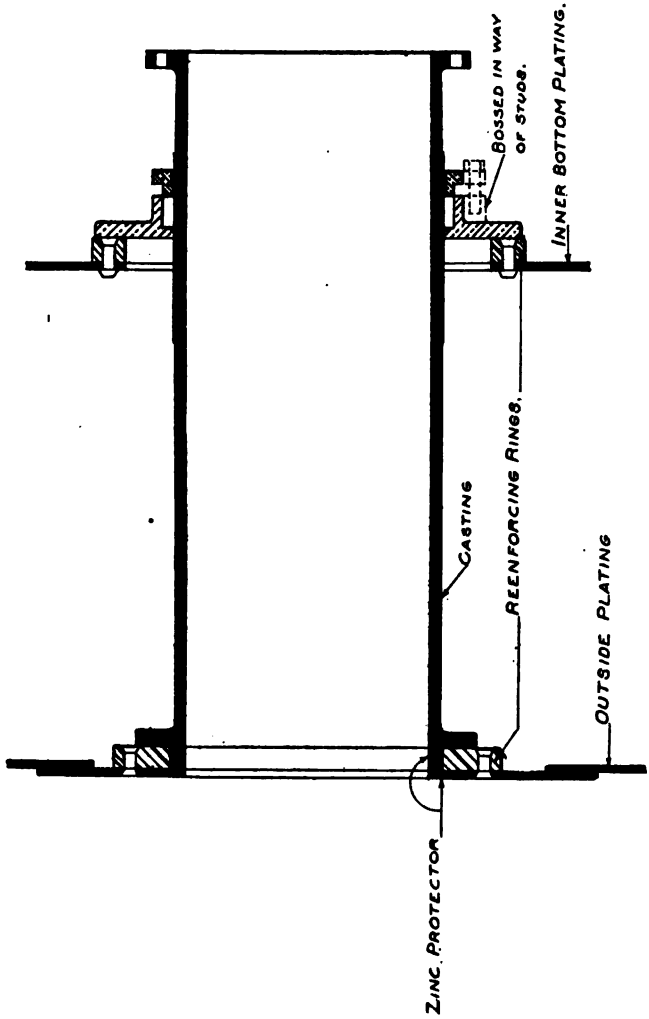

FIG. 134.—OUTBOARD DELIVERY.

ship may be left bare, but that all must be securely protected against rust and corrosion.

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Steel and iron, before applying paint, should be thoroughly dry and clean, as if not dry, the paint will not adhere, and if not clean, corrosion will continue under the paint.

In the U. S. Service, the entire hull, both inside and out, is required to be painted with two or more coats of red lead, on top of which is applied the color paints as required, with two or more coats: white for outside to main deck line; spar color above, and white or other colors inside, except for coal bunkers. The coating of all steel, therefore, is with four coats of paint.

Wherever any fitting of brass or other copper alloy is attached to or adjacent to the steel structure under water, an electric current, such as referred to above, is set up if the paint comes off, and under these conditions, very rapid pitting would take place here. To prevent this, wherever this contact necessarily obtains, strips of zinc are secured to the plating. The current set up then tends to waste away the zinc instead of the steel. These zincs should always be left *unpainted*, and should at every docking be examined, and, if necessary, renewed. (See Fig. 134.)

Fouling.—It is necessary in considering the outside plating below the waterline, in addition to providing against corrosion, to provide against the attachment of animals and marine growths. This attachment is termed *fouling*, and when fouling occurs, the increase of resistance is so great as to seriously decrease the speed, or increase the horsepower and coal consumption to maintain the same speed.

Copper is probably the most efficient anti-fouler, as, under the action of sea water, certain salts are formed which wash off, carrying with them any growth which has become attached. This action is called exfoliation.

When wooden ships were built, copper was, of later years, always fitted, but with the introduction of iron and steel ships, this is not practicable, so that sheathed ships, such as the *Denver*, have to be built, or composite ships on which copper can be fastened, or for ordinary steel ships, dependence put on anti-fouling compositions, which will be treated of later.

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Composite.—*Dubuque:* In this class, as will be seen from Chapter XIII the outside plating below waterline is limited to the flat

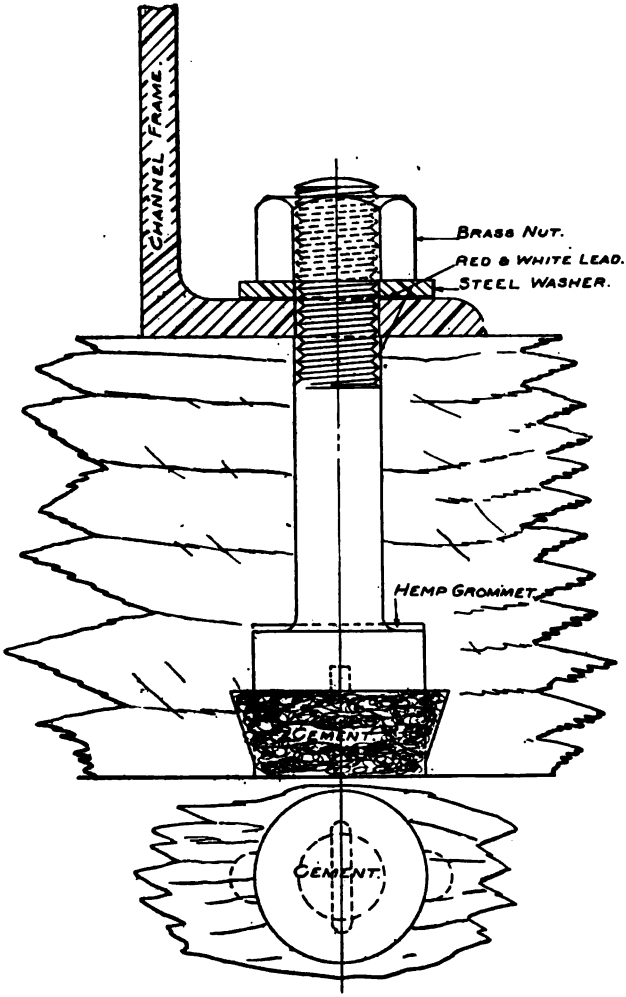

FIG. 135.

el, garboards, and plating in wake of hull fittings. These vessels e planked in one thickness, 4 inches thick, the plank secured to e frames by $\frac{7}{8}$-inch naval brass bolts, the hole for the bolt filled

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with Portland cement, and the whole outside surface of plank below W. L. covered with copper from 24 to 28 ounces. (See Fig. 135.)

This type of construction is not structurally strong and is only applicable to small craft, such as the *Dubuque*.

For larger ships for foreign service, where docking facilities are not available, the ship is constructed in the usual manner, with shell complete, of steel, and on top of this is fastened wood sheathing. This is the system of construction employed in the *Denver* class. By this means we get a ship structurally as strong as a steel ship, with the advantage of copper sheathing.

It is essential that there should be insulation between the copper and the steel skin. In foreign services it was formerly the practice to fit the wood sheathing in two thicknesses, but this has since been abandoned in foreign services for the sheathing in one thickness, which is the method that has always been adopted in the U. S. Service.

The general features of this sheathing are as follows:

(1) The planking is in one thickness, 4 inches thick finished, reduced to 3½ inches at ends. The butts of this planking are shifted with not less than two passing strakes.

(2) The plank is fastened with ¾-inch naval brass bolts, screwed through the plating between the frames, and fitted with brass nuts, the heads of these bolts being recessed in the plank as in the case of deck bolts. Hemp grommets are soaked in red lead and fitted under heads of bolts. Similar hemp grommets are fitted over the points, a steel washer put on top, and the brass nut fitted.

(3) All shell plating is thoroughly tested for watertightness before the planking is worked.

(4) All fitting, fairing, and fastening of planks is carefully done. The faying surfaces are coated with suitable compositions before fitting plank, and after planks are fitted, red lead putty is injected behind planks to fill any spaces that may have been left. The recess for bolt head is filled with cement to prevent the copper sheathing nails coming into contact with bolts and destroying insulation.

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Fig. 136 shows method of fastening above described.

Sheathed vessels require the use of bronze stems, sternposts, etc., to prevent galvanic action. Manganese bronze is generally used in the U. S. Service for this purpose, giving most suitable results as to strength, etc.

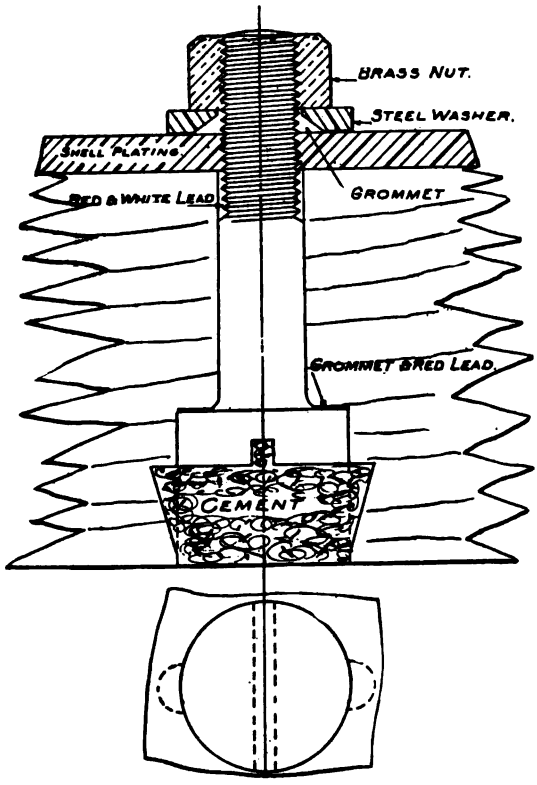

FIG. 136.

The surface of plank is payed with pitch, covered with tar paper, and then with copper sheets which are fastened with composition nails about 1¼ inch long.

In the U. S. Service, the *Denver* class is the only class of sheathed ships we have. There are several examples of composite ships,

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and specifications were prepared and contracts let for a class of sheathed battleships and of sheathed armored cruisers, which, however, were later changed to unsheathed ships, as a careful consideration of the question led to the belief that the additional cost and decreased speed entailed by fitting sheathing on vessels of this class for the purposes of the U. S. Service, were more than were justified by the advantages gained.

For unsheathed ships it is necessary to rely on anti-fouling compositions to prevent fouling; of these there are many. At each navy yard in the United States there is a paint board constituted by authority of the Navy Department, who carefully examine and report on the condition of the bottom of every vessel at the time of docking. This report, together with the length of time the vessel has remained out of dock, and her itinerary prior to docking, and probable location and service after docking, determines the recommendation of the Board as to the kind of composition most suitable for any particular vessel and service.

The usual basis of these anti-fouling compositions is either copper, which, in a soapy form, acts much as does sheet copper, and in exfoliating throws off the marine growth, or arsenic, or mercury, or other poisonous matter which kills the growth.

An iron or steel ship, not sheathed, requires frequent docking and renewal of the anti-fouling composition, as its efficiency as a preventive of fouling soon wears away. In the U. S. Service it is customary to dock at intervals of not more than a year, and generally about every six months.

Prevention of corrosion inside.—We have seen above that no part of the steel structure of a ship may be left bare without serious corrosion and rusting taking place. Examination of the paint work is continually necessary to see if it is properly protecting the steel. This is particularly true of inner bottoms, boiler foundations, and interiors of coal bunkers, when they can be gotten at. Where, on examination, rust is found, or paint abraded, new paint should be applied after suitable cleaning.

Access is provided to each compartment of a ship either by doors or manholes.

As we have seen in Chapter XIV each compartment is numbered,

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and there is furnished to each ship a small booklet plan on which is indicated the means of access to the various compartments.

The following quotation from the Navy Regulations indicates the course prescribed for examining the hulls of vessels:

"1636. (1) The captain of every iron or steel ship shall appoint a permanent board of three line officers, one of whom shall be an engineer officer of the ship, for the purpose of examining and reporting upon her condition, especially as regards deterioration of the inner bottom and vertical bulkheads of boiler compartments, corrosion at the waterline, and of the underwater exterior of the ship, including valves, propeller, rudder, and all other fittings each time they are accessible. They shall also examine and report upon all parts of the top sides, inner hull, and double bottoms, at some time during the quarter; the interval between two successive inspections to be not more than four months. The board shall also report upon the efficiency of all steam and hand pumps within the ship, requiring them to be tested, both for draining the bilges and for fire purposes.

(2) Where practicable, the officers composing this board shall be other than those designated in Article 1637, paragraph 2, as directly responsible for the care and preservation of the ship, but they shall be assisted by such other persons as may be necessary for the efficient performance of their duties. The reports of the board shall be forwarded to the Department for the information of the Bureau of Construction and Repair.

(3) The report by the permanent board shall include a statement as to the structural condition of all valves and ports in the underwater outer hull, the rudders, propellers, shaft struts and tubes, torpedo tubes, bilge keels, and other fittings; also the date of last cleaning and painting, the condition of the paint at the time, and the kind of paint or composition used in repainting.

(4) The captain shall cause a book to be kept, to be called the "hull book," in which shall be entered by the officers making them, reports, duly signed, required by Articles 1636, 1637, 1638, 1639, and 1640, paragraph 2.

(5) For yard or station tugs, waterboats, and coal barges, the commandant shall detail an officer to make inspections and reports herein required."

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At suitable intervals, when ordered, complete surveys are made by the naval constructors at navy yards.

Pipes in lower part of ship are always of galvanized iron or steel.

Cement.—Cementing, with Portland cement, in the U. S. Service, is confined to plate laps in outer shell, inside of ship, and elsewhere as necessary, to permit free flow of water to bilge wells, and is always kept as small as possible.

Cement requires careful examination and renewal if cracked as, if water gets behind it, corrosion may go on unnoticed.

Where the cement, to provide proper flow of water to drain suctions, becomes of any thickness, it is mixed with coke to reduce weight.

In applying cement, it must be applied over clean, bare metal, as rust or paint will prevent adherence.

The inner surfaces of reserve feed tanks, trimming tanks, and fresh-water tanks are covered with cement wash.

In living spaces, where one surface of steel is exposed to chilling, sweating is apt to occur, owing to condensation of moisture in air. Such surfaces are cork-painted, a coat of under cork being applied over the red lead, the ground cork being thrown on while the paint is wet, and the white finishing paint applied on top.

REFERENCES.

Standard Instructions for Painting Naval Vessels, issued by the Bureau of Construction and Repair.

Iron Corosion, Andes.

Rustless Coatings. Wood.

Corrosion-fouling and Their Prevention, Newman.

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CHAPTER XVIII.

COALING.

The provision for means for rapidly coaling vessels of war is a matter of great importance. In foreign services, notably the British, a transporter system has been fitted for coaling from alongside. (See Atwood's Warships, Chapter XI). In the U. S. Service some experimenting has been done with certain systems of coaling at sea, in which the collier is towed by the ship coaling, or vice versa, and the bags of coal transported on rope runaways attached between the masts of the two vessels. The results of these experiments up to date have not been such as to justify fitting these systems generally, and the general provisions are for coaling from colliers or lighters alongside.

The general subject of coaling is divided into three important parts:

(1) Getting coal from collier to ships.

(2) Getting coal into bunkers.

(3) Getting coal from bunkers to firerooms ready for use on the boilers.

Owing to the watertight subdivisions of warships, and the protective decks fitted, the two latter are especially difficult.

Getting coal from collier to ships.—In the U. S. Service this has resolved itself into one of three systems: (a) By coaling booms fitted to deck of the warship so as to hoist coal bags (these bags hold about 900 pounds, and are hoisted one, two, or three at a time) and deposit them either on the upper deck, or through trunks on to some lower deck. These booms are so fitted that when swung out they project beyond the side of the ship an amount sufficient to plumb or nearly plumb the hatch of a collier or lighter, and the falls are so led that the process of hoisting also swings the boom into a position such that it plumbs the trunk referred to above, or lands the bags on the deck in a suitable location, if to be landed

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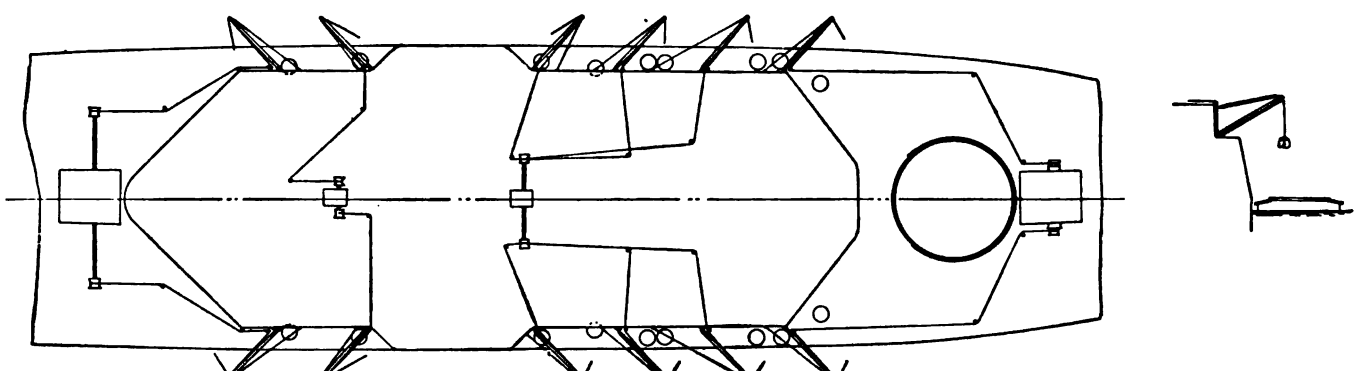

FIG. 137.—COALING WITH BOOMS.

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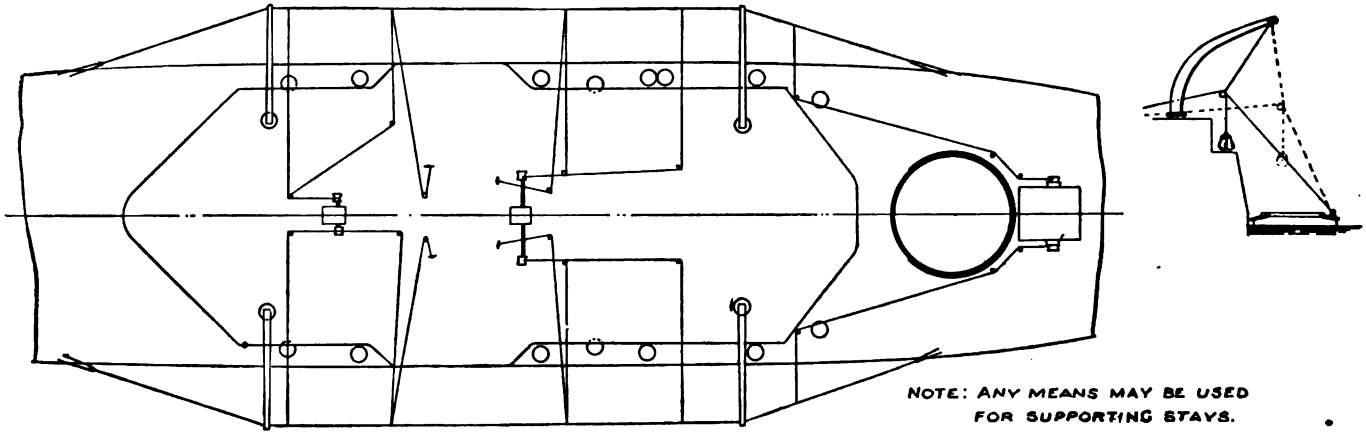

FIG. 138.—COALING WITH TRIATIC STAYS.

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on the upper deck. The hoisting is done by electric winches, fitted with double drums, of which there are generally two aft, two on the superstructure, and two forward. (This arrangement is shown in Fig. 137.)

(b) By rigging a wire span from the heads of the boat cranes or other suitable outriggers on which are rove whips by which the coal can be hoisted and lowered on deck as above. (This arrangement is shown in Fig. 138.)

(c) By a combination of (a) and (b).

Getting coal into bunkers.—The considerations determining the location of coal bunkers in warships will not permit of as large, roomy, and accessible bunkers as is the practice in the merchant service.

As we have seen above, it is customary to locate the coal bunkers, part outboard of and abreast the boiler rooms, and part above the berth deck, in which location they furnish a certain amount of protection and interfere less with the stowage of ammunition, etc., than elsewhere. In some ships it is possible to get athwartship bunkers, but in general the location is as above.

Owing to the fitting of armor and guns on the sides preventing the cutting of side ports, and other considerations, the system of coaling over all, or from the upper weather deck, has been developed. Taking a recent battleship, we find on each side, through the deck, six openings, each from 4 ft. 6 in. by 6 ft. to 6 ft. square, fitted with large skylight covers and about equally spaced in a longitudinal direction over the length of the coal-bunker space below. The coal is lowered to the gun deck through these trunks or skylights, and there by trucks wheeled to the dumping place on either side of the ship.

From the gun deck to each lower bunker lead one or more trunks 36 inches square and watertight from gun to berth deck. In the top of each trunk is fitted a round brass scuttle 24 inches in diameter. Where these trunks pass through the upper bunkers, a hinged watertight door 21 in. by 30 in., hinged to swing into the trunk, is fitted to permit coal to be trimmed from upper to lower bunkers. There are fitted to each upper bunker two scuttles in the gun deck. From the gun deck to each fire room is led a

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trunk with a small trimming door, as described above, opening into the upper bunker, by means of which coal may be delivered from the upper bunker directly onto the fire-room floor.

In stowing coal bunkers, it is necessary to provide means for the men stowing the coal to escape, and a small escape door is fitted in the longitudinal bulkhead well up under the protective deck for each of the lower bunkers, and an escape scuttle in the gun deck

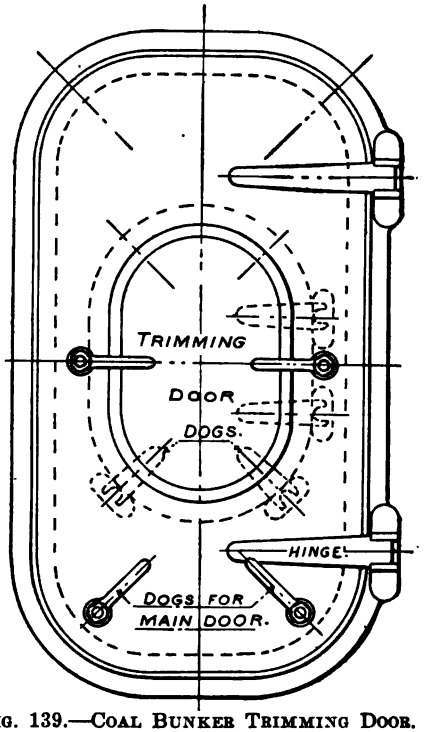

FIG. 139.—COAL BUNKER TRIMMING DOOR.

for the upper bunkers; these are fitted near bulkheads, and rungs are fitted on the bulkheads to get at them.

To permit trimming coal fore and aft within the bunker space, it is usual to fit in the athwartship bulkheads, watertight trimming doors, *i. e.*, watertight doors having small doors inside them, one

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door swinging one way, and the other the other way. (See Fig. 139.)

I-beam trolleys are fitted fore and aft, having hinged portable pieces in wake of these doors, and on these are run trolleys carrying coal buckets. (See Fig. 140.)

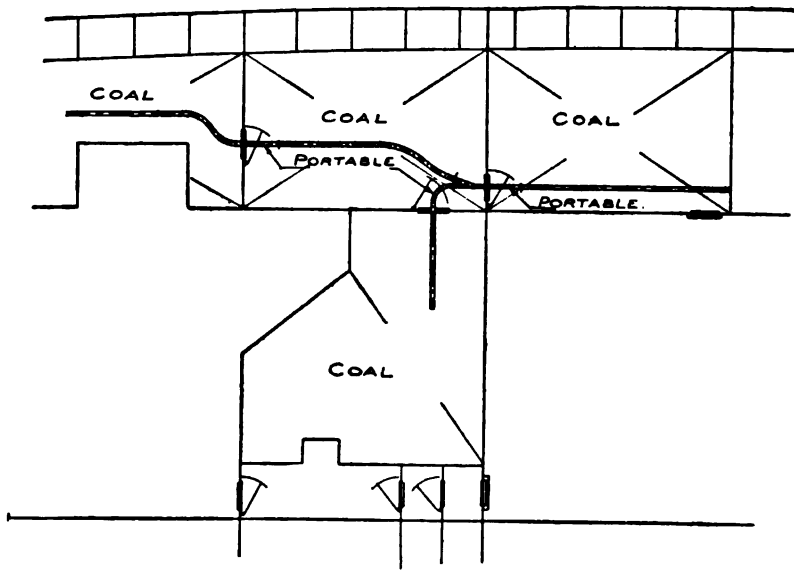

FIG. 140.—TROLLEY TRACKS IN COAL BUNKERS.

Getting coal from bunker to fireroom.—For the lower bunkers, there is fitted to each fireroom a door to each lower bunker adjacent to that room. These doors are of the vertical, sliding, watertight type, and operated by electric power or by hand.

After the coal has been used from the lower bunkers, it has to be trimmed down from the upper bunkers, and is either trimmed directly to the fireroom floors, or into the lower bunkers through the trimming doors in the trunks leading to the lower bunkers, both as explained above.

Care must be taken to screen the watertight doors to prevent the

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coal jamming them, so they canot be opened or *closed*. These screens are as shown in Fig. 141.

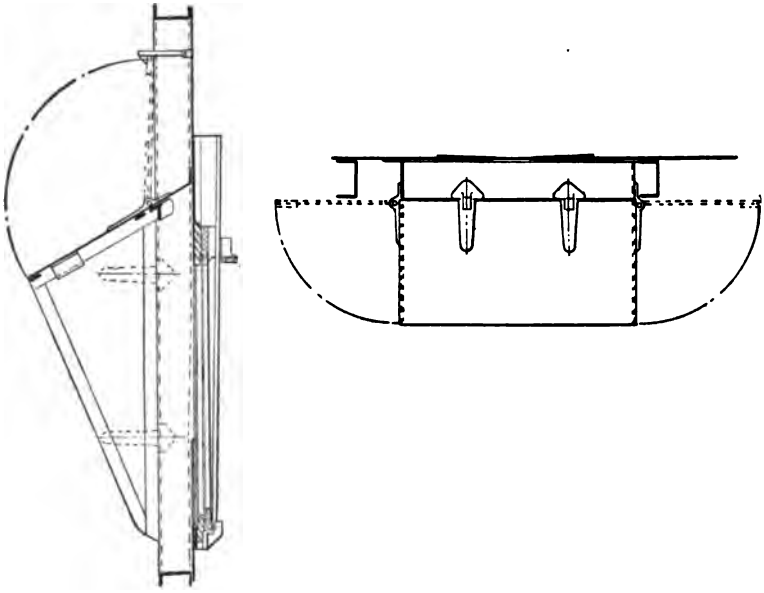

FIG. 141.—SCREEN FOR COAL BUNKER DOOR.

Two sides support a sloping top plate, keeping the coal from the door; these are all hinged so that when the door is free from coal, the side plates may be hinged aside and the top plate hinged up out of the way.

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CHAPTER XIX.

AUXILIARY MACHINERY, DRAINAGE, FLOODING, AND PUMPING.

Although ordinarily treated in a book of this character, in order not to duplicate the student's work, the author omits touching on such auxiliary machinery as is treated in Barton's Naval Engines and in the other text-books which form a part of the course at the Naval Academy. This includes steering gears, capstans, turret-turning machinery (treated in Naval Engines, Chapter XIV), ammunition hoists, and auxiliaries used in connection with hoisting ammunition. (See Fullam & Hart on Ordnance and Gunnery, Chapter XXX). It should be noted, however, that the latest types of boat cranes and deck winches are electrically operated.

Boat cranes.—These are built-up cranes of box section, formed of plates and angles. The weight of crane is carried by a roller bearing at main deck level, with a guide bearing at the deck above this, and a step bearing at the deck below for the heel of the crane. A platform attached to the crane revolves with it and carries on it two electric motors, one of about 30 H. P. for rotating, and one of 50 H. P. operating a winch for hoisting the boats, each with suitable controlling apparatus. This hoisting winch is fitted with two brakes, one mechanical and one electrical, to prevent dropping the boat from any cause. The character of such a crane is shown in Fig. 142.

Deck winches.—The latest type of deck winch is also operated by an electric motor, but mechanically it does not differ essentially from the steam-driven type.

Drainage, flooding, and pumping.—These are treated at some length in Barton's Naval Engines, Chapter XII, and while the systems vary somewhat from ship to ship, the principles there outlined, and the general arrangements, are similar to those found on other modern ships.

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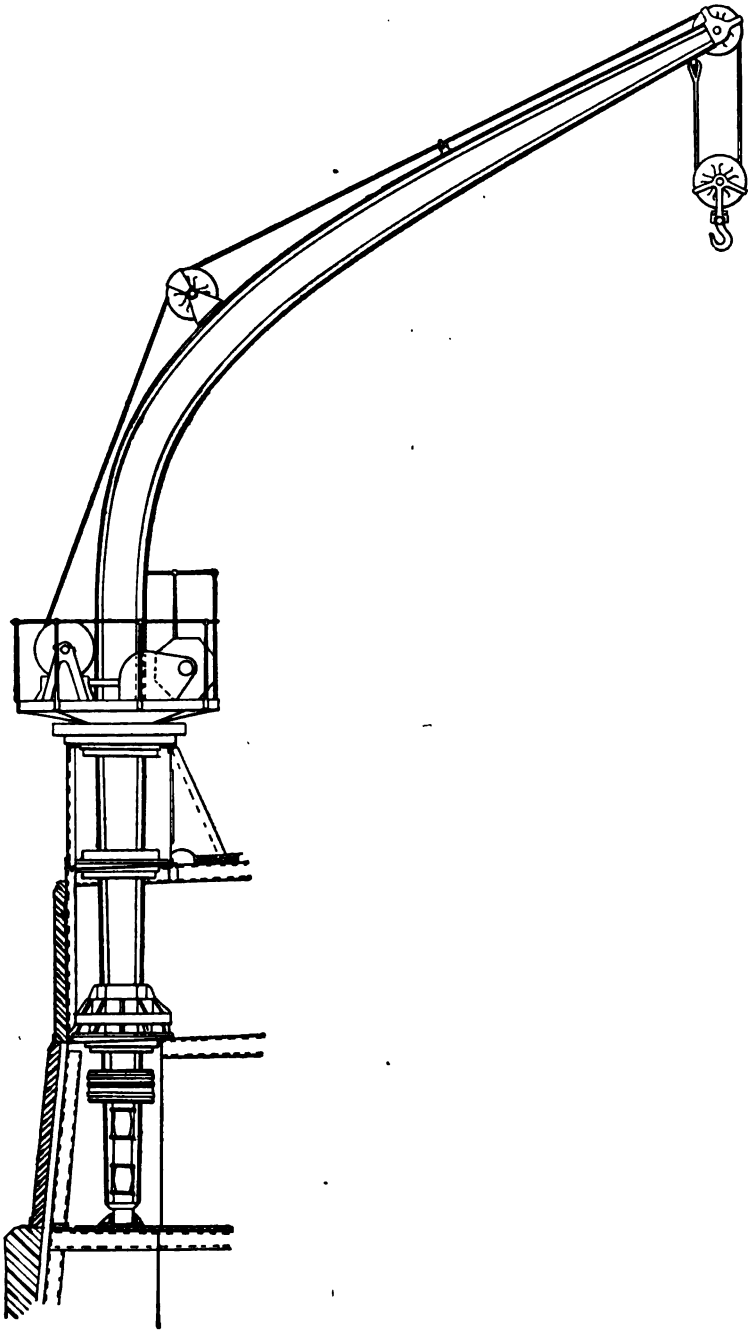

FIG. 142.—BOAT CRANE.

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In addition to the drainage system described there, however, it should be noted that there is fitted to each ship a system of natural drainage, or scuppers, for carrying off water which finds its way to the upper or weather decks. This is a system of pipes, vertical or nearly so, with outlet located at the lowest point of the space to be drained, and discharging overboard above the waterline.

REFERENCES:

Specifications for U. S. ships.

Specifications for Electric Appliances under the Bureau of Construction and Repair.

Test Reports, obtainable at the Bureau of Construction and Repair.

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CHAPTER XX.

ARMOR AND DECK PROTECTION.

Modern warships are liable to three forms of attack: Ramming, torpedo and mine attack, and gun fire. Of recent years, ramming has not been much employed, and the experience of the Russo-Japanese war indicates that in all probability it will not be.

Against ramming and torpedo attack, the protection requires to be provided below the waterline, and has generally taken the form of minute watertight subdivision, though some ships have thin under-water armor distributed in various ways. The protection against mines and torpedoes is now (1906) receiving much attention from naval constructors.

The most serious form of attack, however, is the gun fire. As a protection against this, armor is fitted over as large a part of the outside area of the vessel as possible, and over gun positions. Coal is distributed at the sides to assist the armor. The places unprotected by armor are minutely subdivided near the waterline, to localize the damage, and thick decks are fitted, near waterline and above, to protect certain vital parts.

The protection takes two general forms:

(1) Protection to armanent and personnel.

(2) Protection of buoyancy and stability.

In a recent U. S. battleship of 16,000 tons, 4014 tons are armor, and of this, 1820 tons are for protection to armament, and 2194 tons for protection to buoyancy and stability.

The building of armored ships of modern type (not including monitors) practically began in the U. S. Service with the construction of the *Texas* and *Maine* in 1889 to 1895. So that in the beginning the United States had, to a certain extent, the benefit of much of the experience of foreign services in the arrangement of guns and distribution of armor.

We may trace the development of this, generally, by taking typical ships from the time of the *Texas* to the latest type:

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Texas—1889-1895: 301″ 4′ × 64″ 1′ × 22″ 6′ draft; displacement, 6327 tons. The waterline belt armor is 12 inches thick at top and 6 inches at bottom, of Harveyized type; the redoubt is 12 inches thick, the diagonal 8 inches thick, and the turrets 12 inches thick, nickel steel. (See Fig. 143.)

Here we see the echelon arrangement of turrets, the thick, narrow waterline belt, and the flat protective deck.

Massachusetts—1890-1896: 348′ × 69′ 3″ × 24′; displacement, 10,163 tons. The waterline belt is 18 inches at top and 8½ inches at bottom; the diagonal armor is 14 inches thick; the casemate side and diagonal, 4 inches; the 13-inch barbettes are 17 inches, the 8-inch barbettes, 8″-6″; the 13-inch turrets are 15 inches, the 8-inch turrets, 6 inches thick. The waterline belt and turrets are of Harveyized type, and the remaining armor nickel steel. (See Fig. 144.)

Iowa—1893-1897: 360′ × 72′ 2½′ × 23′ 10⅝″ draft; displacement, 11,275 tons. The waterline belt is 14 inches thick at top, 7 inches at bottom, 14 inches at waterline; the diagonal armor is 12 inches; the casemate is 4 inches; the 12-inch barbettes are 15 inches and 12½ inches thick; the 8-inch barbettes are 8 inches and 6 inches thick; the 12-inch turrets are 17 inches and 15 inches thick; the 8-inch turrets are 8 inches and 7 inches thick. The armor is of the Harveyized type. A flat protective deck is fitted at the berth deck level amidships, and at the upper platform level, forward and aft. Here is seen an increase in freeboard forward, adding to the weatherly qualities of the vessel. (See Fig. 145.)

Kearsarge—1896-1900: 368′ × 72′ 2½″ × 23′ 10½″ draft; displacement, 11,724 tons. The waterline belt is 16½ inches thick at top, 9½ inches at bottom, and 13¾ inches at waterline, reduced to 4 inches thick forward; the triangular and athwartship is 12 inches; the casemate is 5 inches at side and 4 inches athwartship; the superstructure armor is 6 inches; the barbettes are 15″-12½″ thick; the turrets, 17″-15″-11″-9″ thick. The armor is of the Harveyized type. The protective deck is flat amidships, sloping at ends. This is the first type of battleship with superposed turrets, and we again see the low freeboard of the earlier *Massachusetts* class. (See Fig. 146.)

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Alabama—1896-1900: 368′ × 72′ 2½″ × 23′ 8½″ draft; displacement, 11,703 tons. The waterline belt is 16½ inches at top, 9½ inches at bottom, 13⅜ inches at waterline, tapering to 14″-11½″-9″-6½″-4″ at top, and to 8″-6¾″-5½″-4¾″-4″ at bottom, forward; the triangular armor is 12 inches; the lower and upper casemate is 5½ inches at side and diagonal; the gun protection on superstructure is 6 inches; the barbettes are 15″-10″ thick; the turrets are 14 inches thick. The armor is of the Harveyized type. The protective deck is flat amidships and sloping at ends. In this type the 8-inch gun has been abandoned and the intermediate battery made of a uniform size of 6 inches. The high freeboard forward again appears. (See Fig. 147.)

Maine—1898-1902: 388′ × 72′ 2½″ × 23′ 9″ draft; displacement, 12,846 tons. The waterline belt is 11 inches thick at top, 7½ inches at bottom, 11 inches at waterline, tapering to 9″-7″-5″-4″ at ends; the lower and upper casemate sides and athwartship are 6 inches; the gun protection on superstructure is 6 inches; the barbettes are 12″-8″ thick; the turrets are 12″-11″ thick. The armor is of the Krupp type, considerably increasing its resisting qualities. The protective deck is flat amidship and sloping at ends. (See Fig. 148.)

Virginia—1902-1906: 435′ × 76′ 2½″ × 23′ 9″ draft; displacement, 14,948 tons. The waterline belt is 11 inches thick at top, 8 inches at bottom, 9 inches at waterline, tapering to 6″-5″-4″ at ends; the triangular armor is 6 inches; the lower and upper casemate at side and athwartship is 6 inches; the barbettes for superposed turrets are 10″-7½″ thick, and the 8-inch broadside barbettes are 6″-4″ thick; the superposed turrets are 12″-8″-6″, and the broadside turrets are 6½″-6″ thick. The armor is of the Krupp type. The protective deck is sloping at sides and ends. This class also has the superposed turret arrangement and a continuous high freeboard. (See Fig. 149.)

Connecticut—1903-1906; 450′ × 76′ 10″ × 24′ 6″ draft; displacement, 16,000 tons. The waterline belt is 11 inches thick at top, 9″ at bottom, 11 inches at waterline, tapering to 9″-7″-5″-4″ at ends; the triangular armor is 6 inches; the lower casemate at side and athwartship is 6 inches; the upper casemate at side and

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athwartship is 7 inches; the 12-inch barbettes are 10″-7½″-6″ thick, and the 8-inch barbettes are 6″-4″-3¾″ thick; the 12-inch turrets are 12″-8″ thick, and the 8-inch turrets are 6½″-6″ thick. The armor is of the Krupp type. The protective deck is sloping at sides and ends. (See Figs. 150).

Kansas—1904-1907: 450′ × 76′ 10″ × 24′ 6″ draft; displacement 16,000 tons. The waterline belt is 9 inches thick, tapering to 7″-5″-4″ at ends; the triangular armor is 6 inches; the lower casemate is 7 inches at side, 6 inches athwartship; the upper casemate at side and athwartship is 7 inches; the 12-inch barbettes are 10″-7½″ 6″ thick, and the 8-inch barbettes are 6″-4″-3¾″ thick; the 12-inch turrets are 12″-8″ thick, and the 8-inch turrets are 6½″-6″ thick. The armor is of the Krupp type. The protective deck is sloping at sides and ends. (See Fig. 151.)

New Hampshire—1905-1908: 450′ × 76′ 10″ × 24′ 6″ draft; displacement, 16,000 tons. The waterline belt is 9 inches thick, tapering to 7″-5″-4″ at ends; the triangular armor is 7 inches; the lower and upper casemate at side and athwartship is 7 inches; the 12-inch barbettes are 10″-7½″-6″ thick, and the 8-inch barbettes are 6″-4″-3¾″ thick; the 12-inch turrets are 12″-8″ thick, and the 8-inch turrets are 6½″-6″ thick. The armor is of the Krupp type, except the upper casemate and turrets, which are of the Midvale Process type. The protective deck is sloping at sides and ends. (See Fig. 152.)

We also have 1904-1907 the *Idaho* class (Fig. 153), modified *Kansas*, with less speed, but possessing no special features except the cut-down deck aft.

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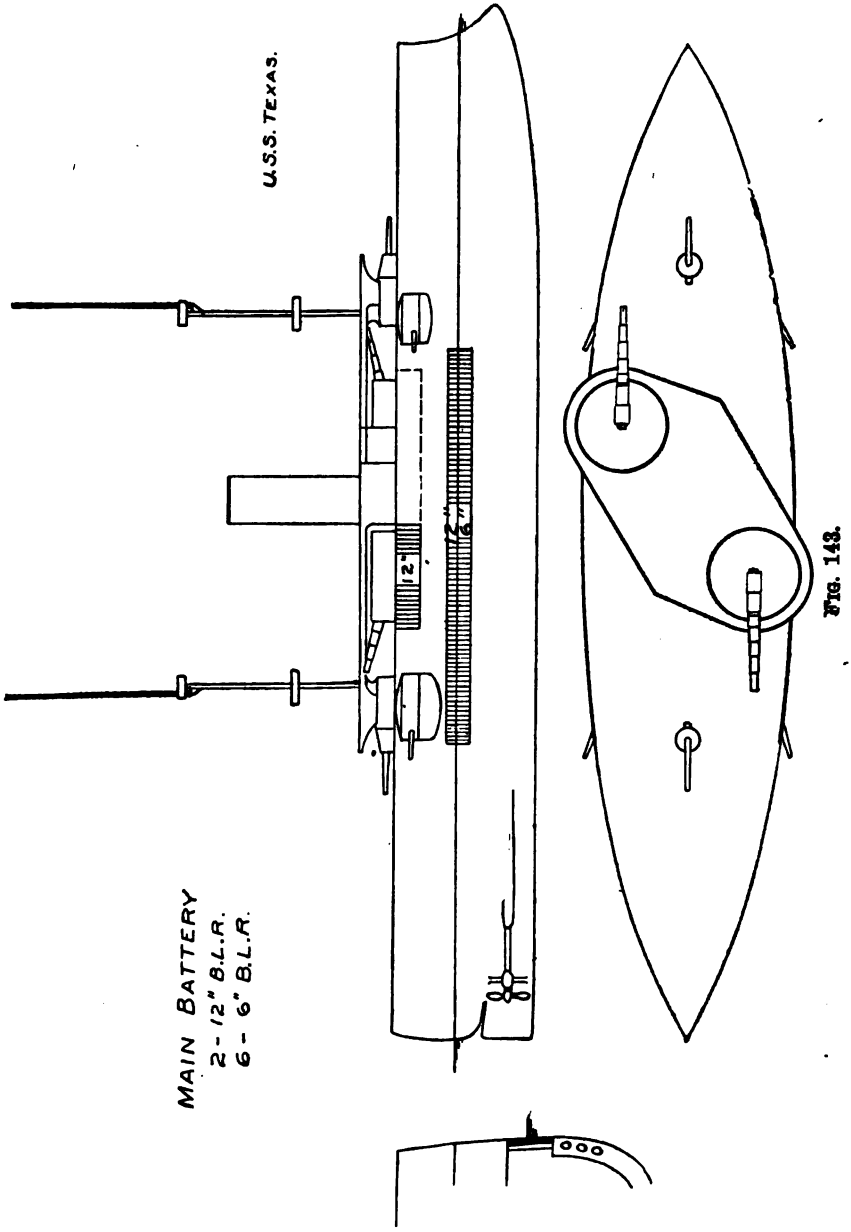

FIG. 143.

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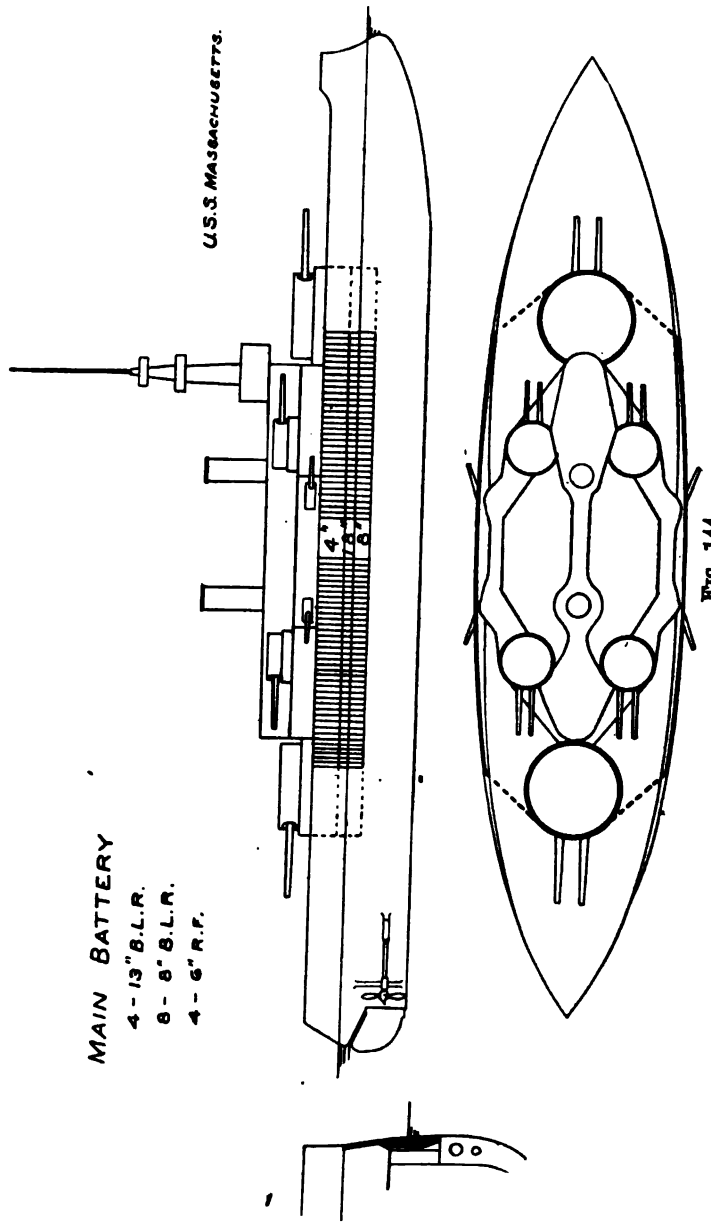

FIG. 144.

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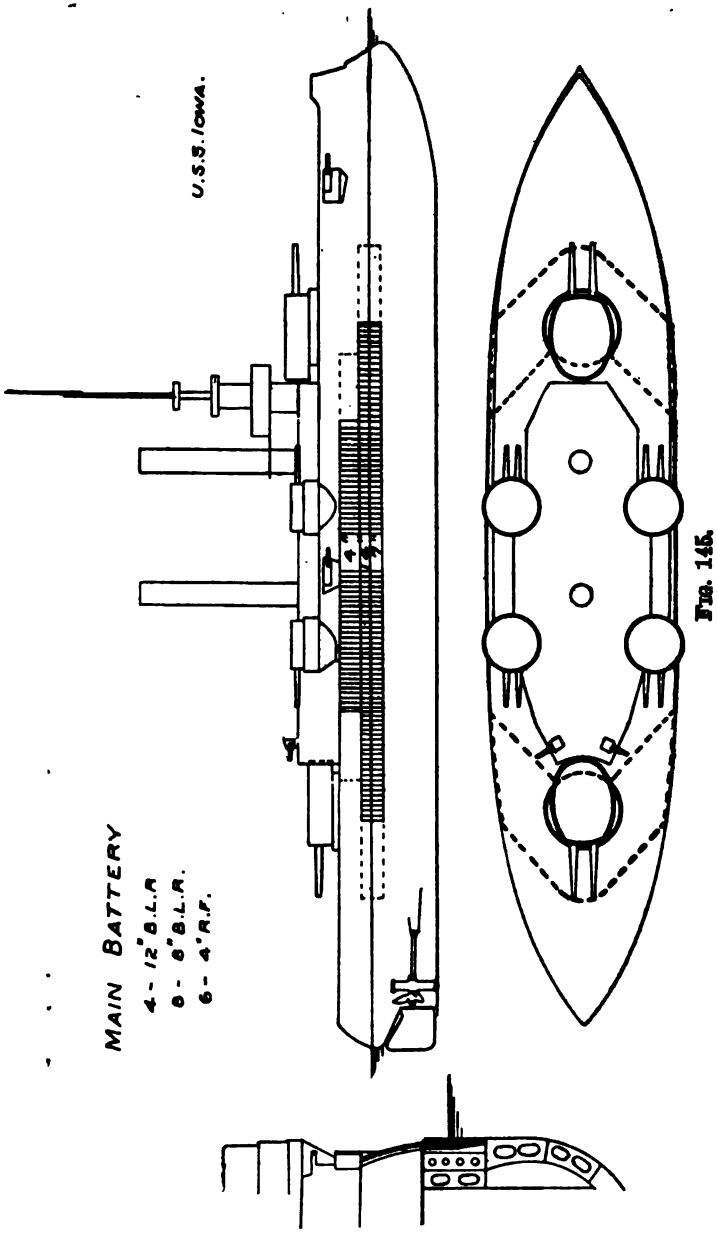

FIG. 145.

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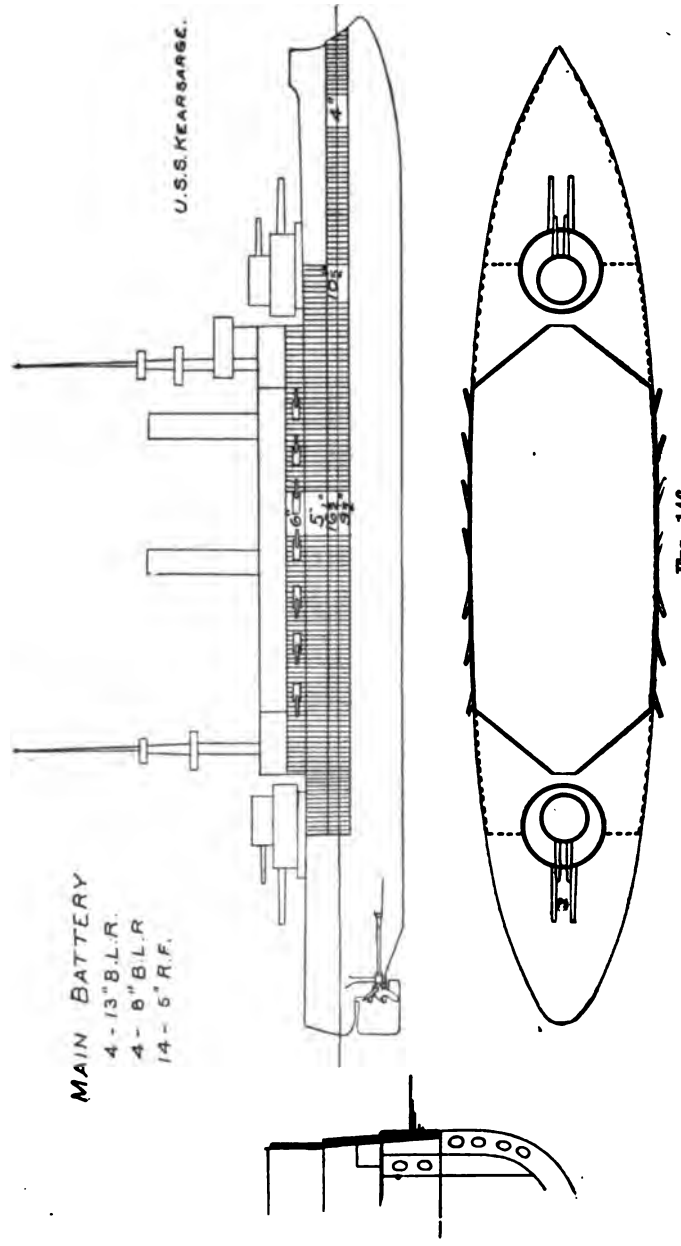

FIG. 146.

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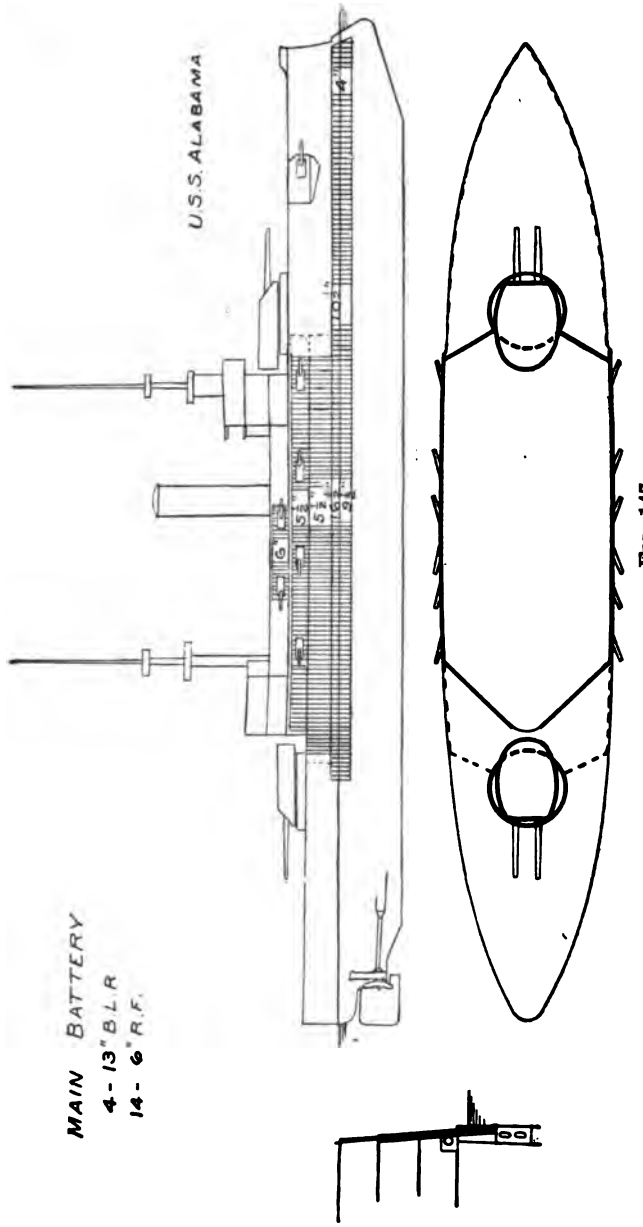

FIG. 147.

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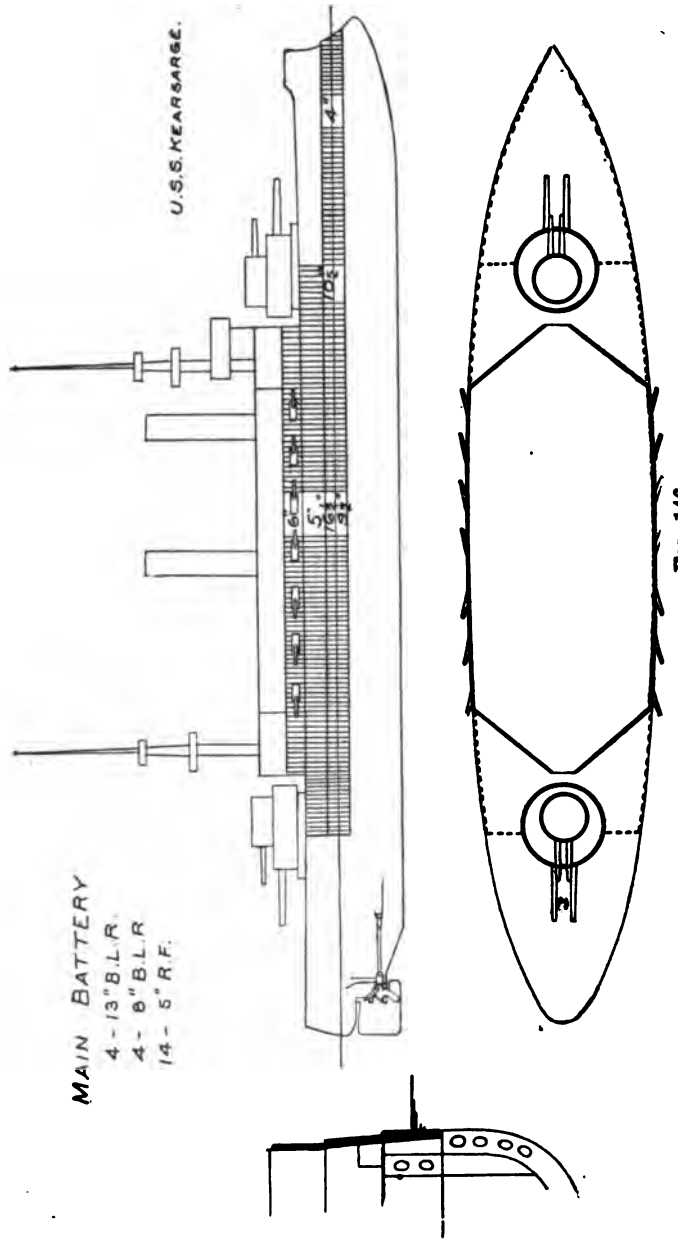

FIG. 146.

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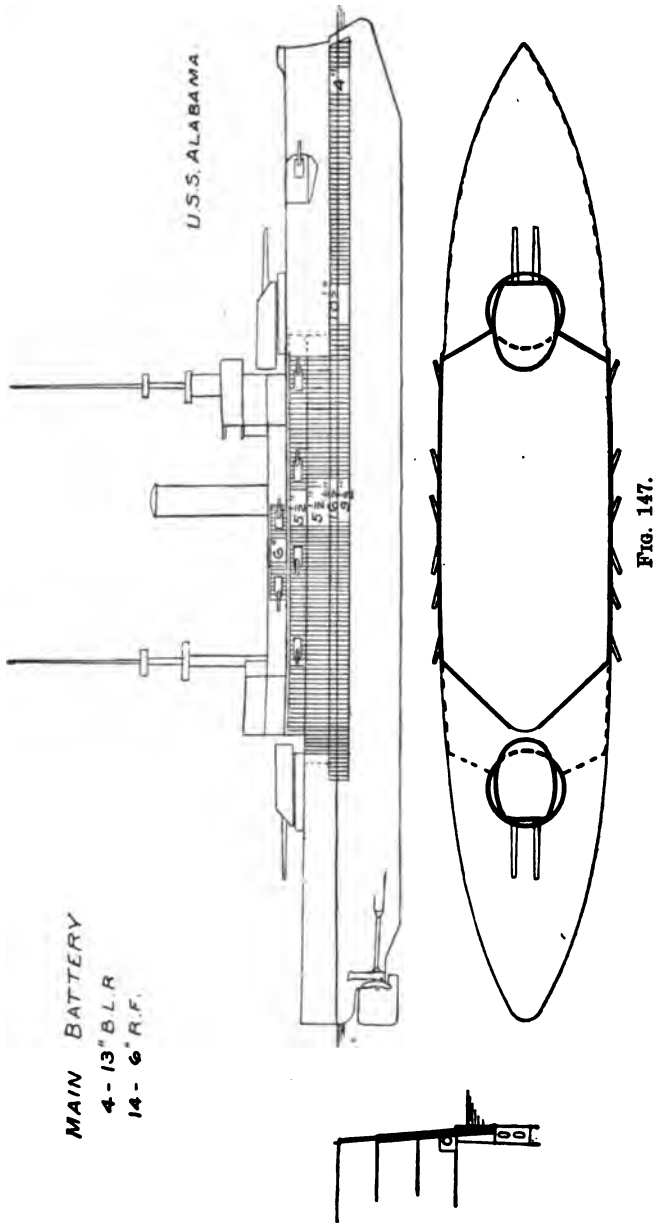

FIG. 147.

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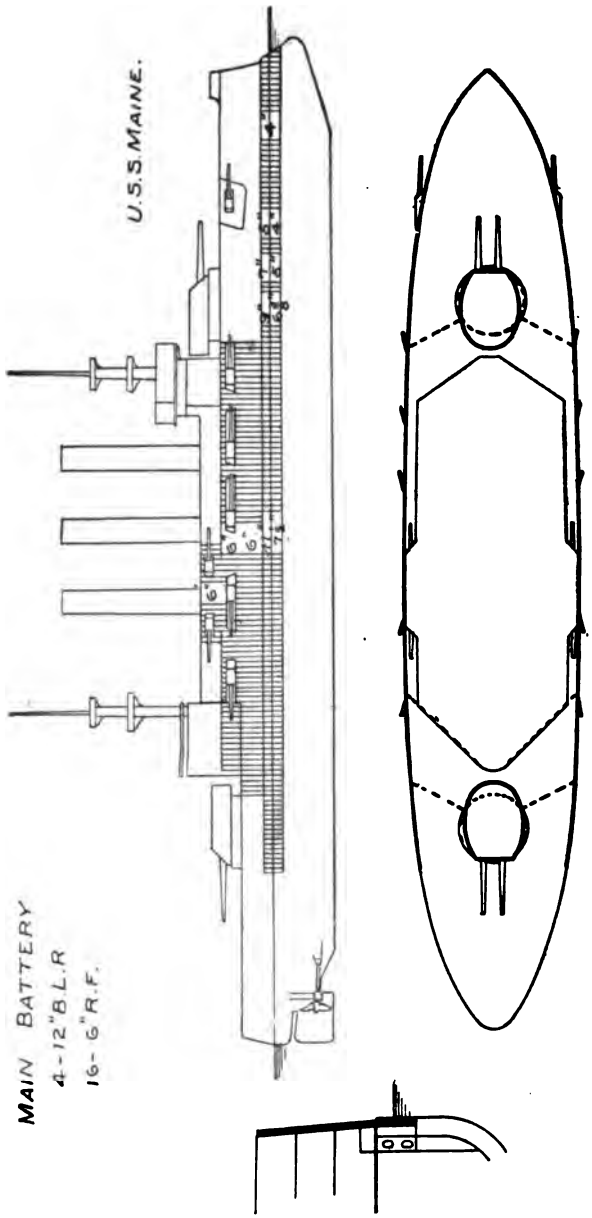

FIG. 148.

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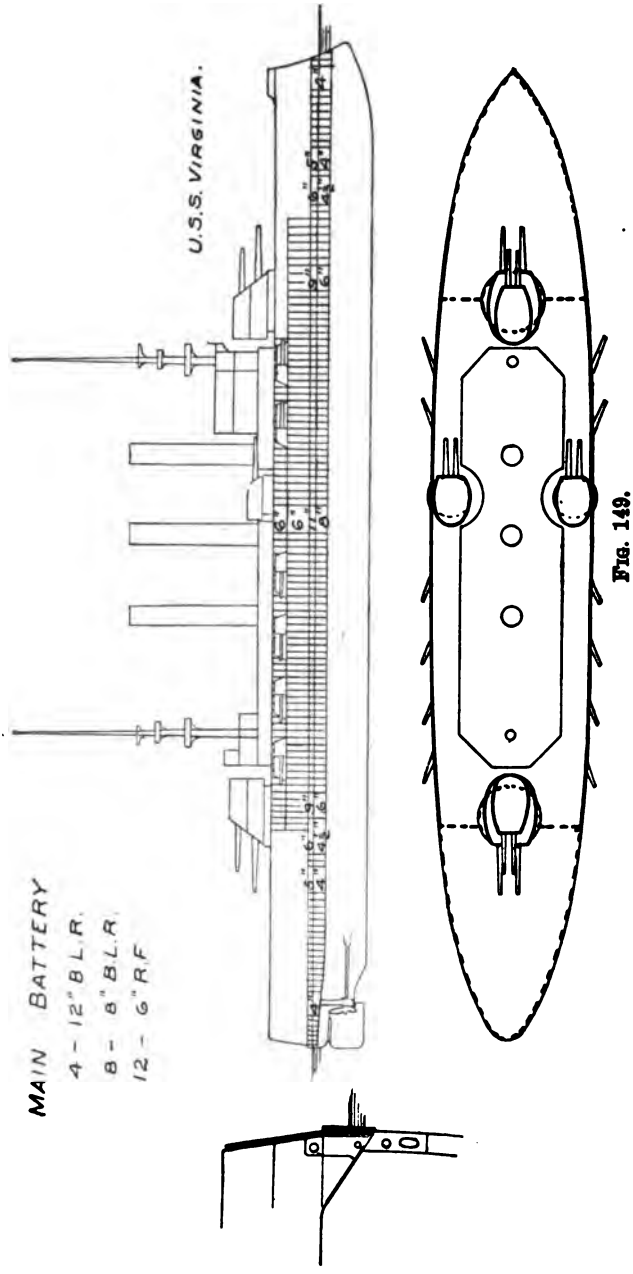

FIG. 149.

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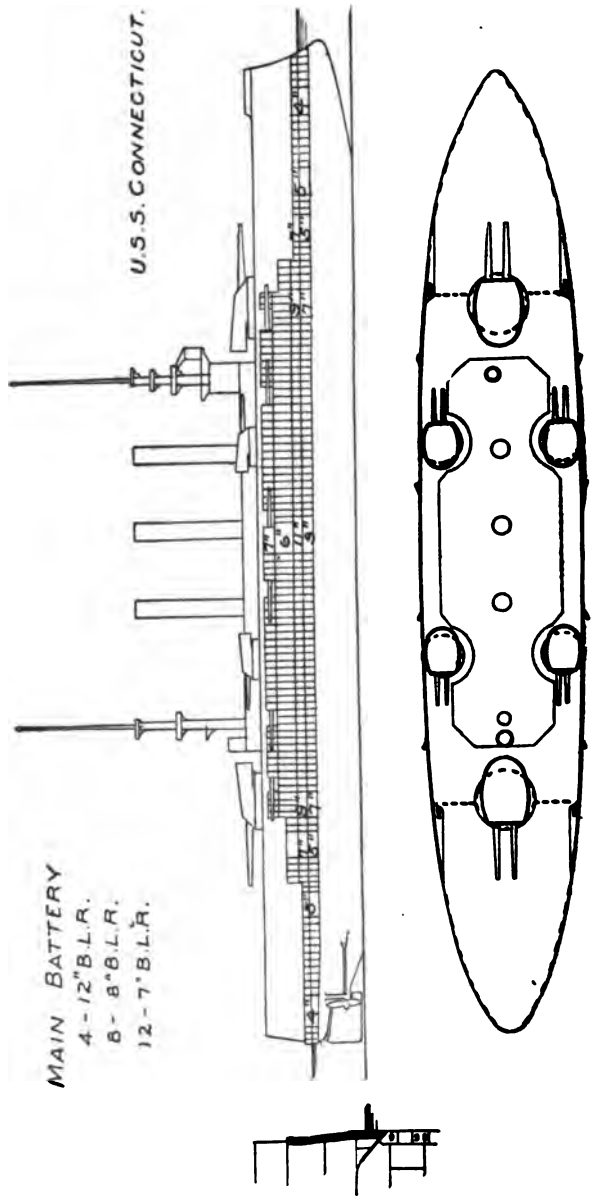

FIG. 150.

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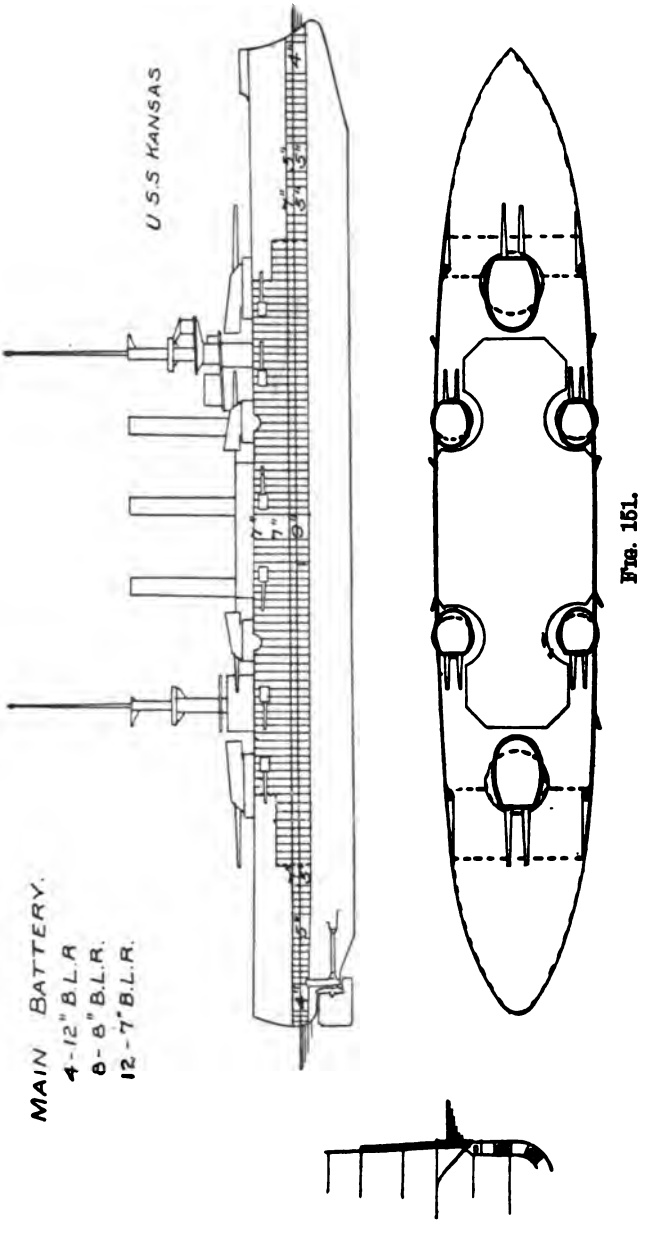

FIG. 151.

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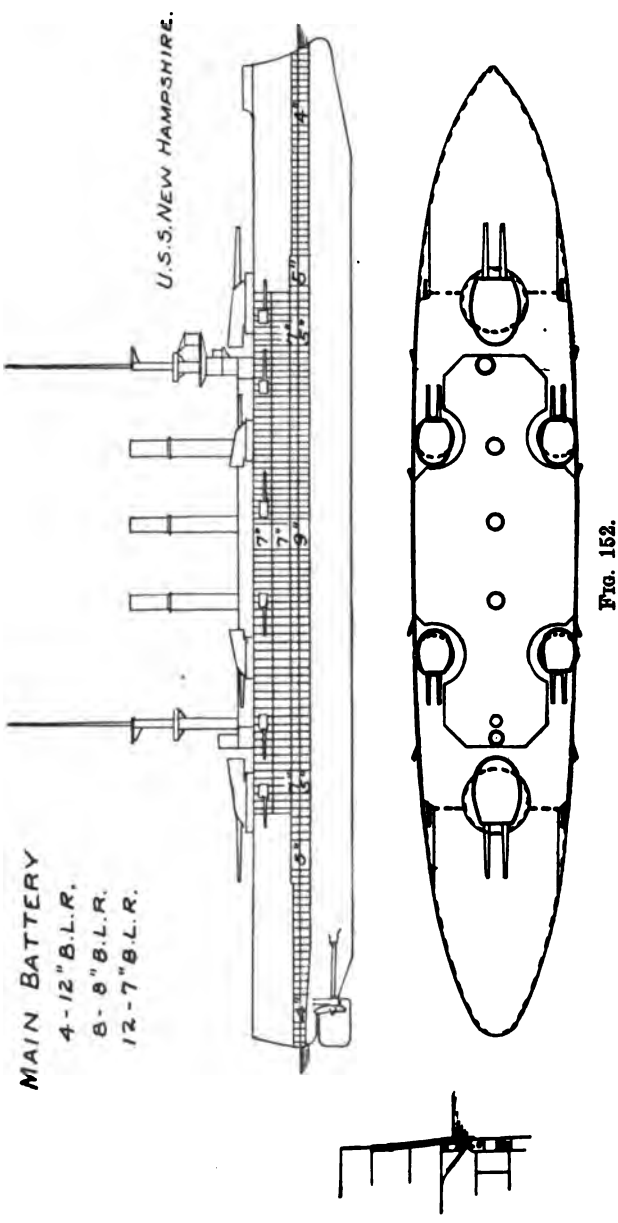

FIG. 152.

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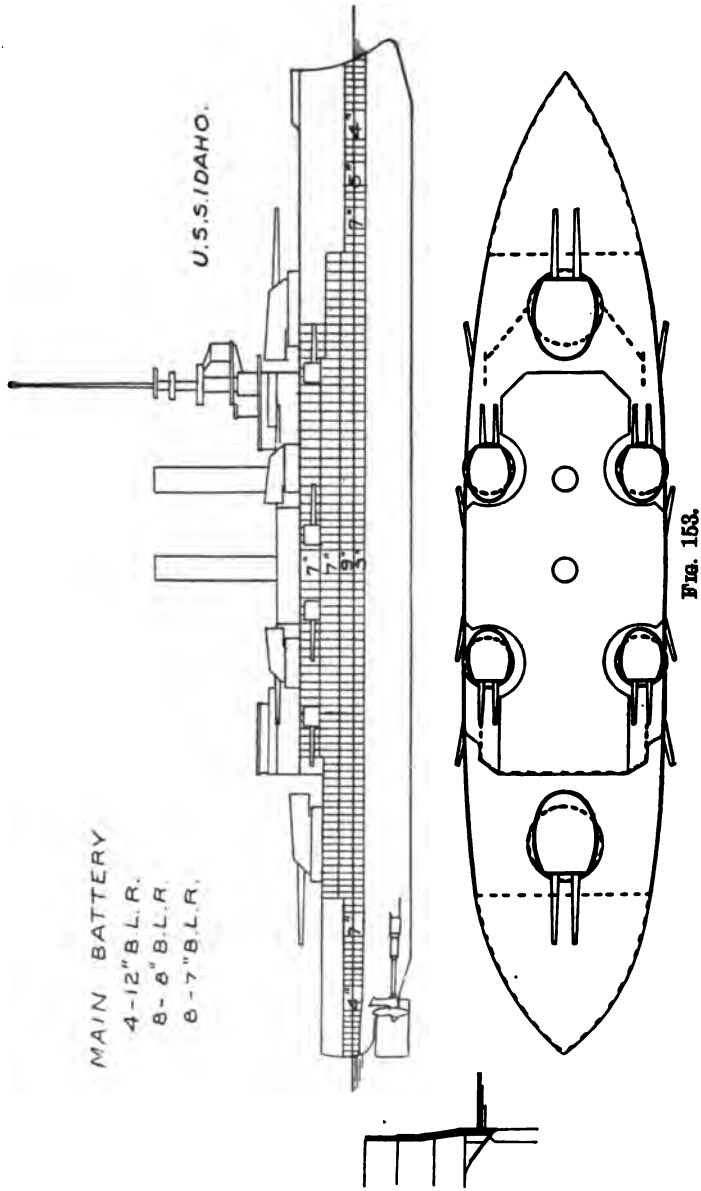

FIG. 153.

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Armor Hatches, Gratings, Etc.

In protective decks, many openings are necessary for access to spaces below, etc., which require to be closed in action. Such openings are usually closed by hinged covers, having the same thickness as the adjoining deck. Such hatches are operated by hand screw gears, electric power, or on the balanced system. Types of the screw gears and balanced system are shown respectively in

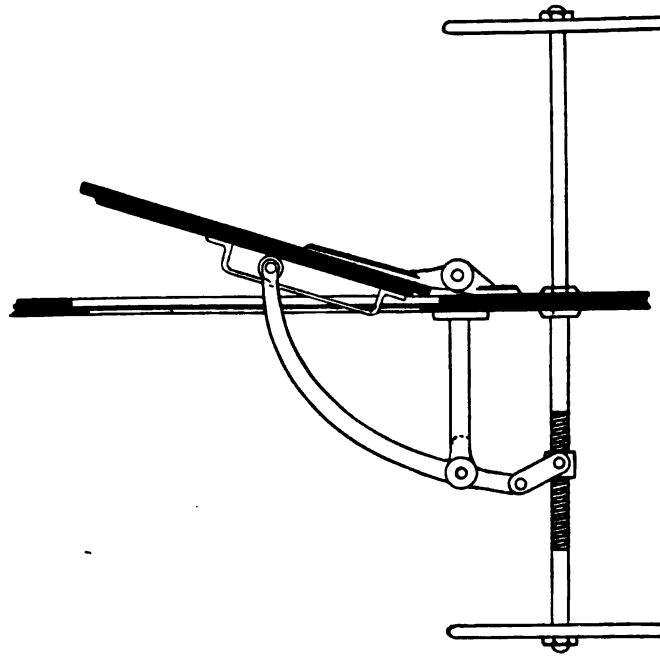

FIG. 154.—SKETCH OF HATCH OPERATED BY SCREW GEAR.

Figs. 154 and 155, and the electric type is essentially the screw type operated by an electric motor.

A number of the openings in the protective deck require to be open even in action, such as openings for smokestacks, ventilators, etc., and into these armor gratings are fitted. A type of such gratings is shown in Fig. 156.

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The opening is divided into rectangular spaces by girders, and into each of these spaces, gratings are fitted. The bars are supported as shown, and for a 1½-inch deck, are 6 inches deep by 1 inch thick.

Some of these gratings require to be lifted for access to below, and the sections requiring to be lifted are then hinged and fitted with a rope hoisting device, and by winding up the rope on a drum, the grating hatch is raised as required.

Cofferdams.

Around the sides of the ship, extending behind armor, from protective to berth deck, and outside of armor to some 3 feet

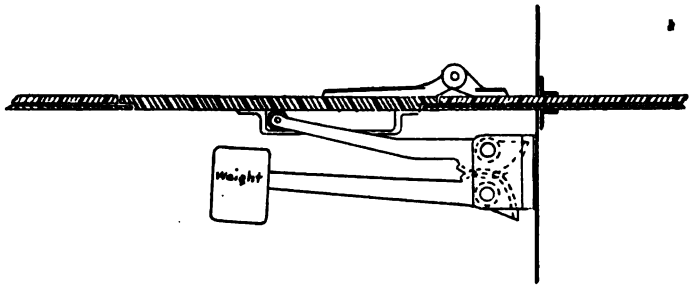

FIG. 155.—SKETCH OF BALANCED HATCH.

above berth deck, are fitted hollow watertight boxes about 30 inches in depth from side of ship, called *cofferdams*. These are filled with cellulose, made from corn-pith, fireproofed, and compressed in blocks to a density of 8 pounds per cubic foot. When water gains access to these spaces, the cellulose swells up, closing the opening and preventing further flooding.

Protection of Cruisers.

The principal qualities to be obtained in a cruiser are high speed and large coal capacity. This necessarily limits the weight available for protective purposes.

The early cruisers of the U. S. Service, from the time of the

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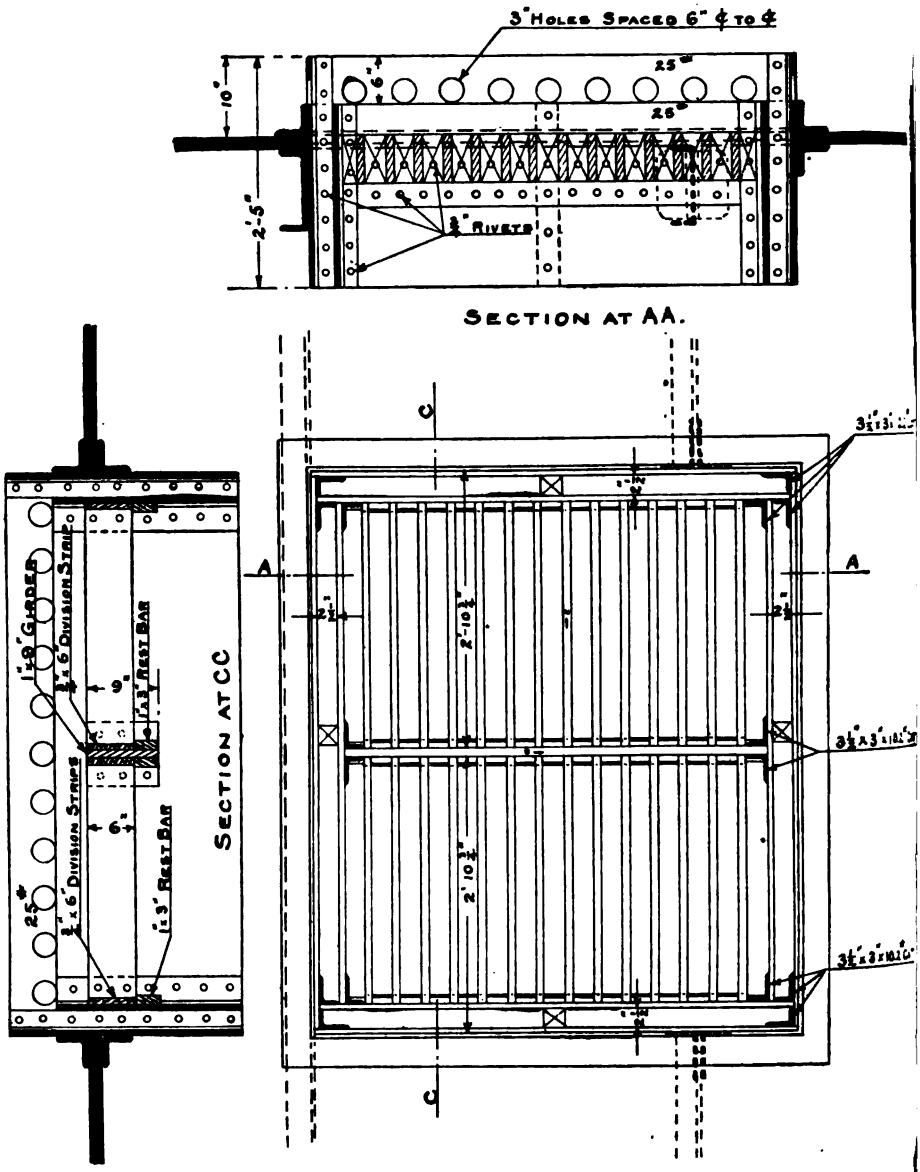

FIG. 156.—ARMOR BAR HATCH IN PROTECTIVE DECK.

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Boston, had no protection, except a protective deck and that given by coal and isolated protection to gun positions.

The *New York* had a narrow waterline belt of 4-inch armor, 8 feet wide, extending over about one-half the length, and a sloping protective deck varying in thickness from 2½ to 6 inches. This, with the armor for gun positions, constituted the armored protection.

The *Brooklyn* was of the same general type. (See Fig. 86.)

A narrow belt of this kind is apt to be entirely submerged when the ship rolls.

The *Pennsylvania* class of armored cruisers, and the *Washington* and *North Carolina* class, represent the present-day ideas, and by examining Figs. 157, 158, and 159 we see that the distribution of protection is very similar to that on a battleship, though not so thick. Here we find, in the case of the *Pennsylvania,* a complete waterline belt of armor 6 inches thick at top and 5 inches at bottom, for a length of about 232 feet abreast the engines and boilers, and of a uniform thickness of 3½ inches forward and aft of these spaces, to bow and stern; a lower and upper casemate 5 inches thick at sides and 4 inches thick athwartships; the barbettes 6 inches thick, and the turrets 6½"-6". In the case of the *Washington,* a complete waterline belt of armor 5 inches thick for a length of about 330 feet abreast the machinery and magazine spaces, and 3 inches thick forward and aft of these spaces, to bow and stern; a lower and upper casemate 5 inches thick at side and athwartship; the barbettes 7"-4" thick, and the turrets 9"-7"-5". In the case of the *North Carolina,* a complete waterline belt of armor, 5 inches thick for a length of about 334 feet abreast the machinery and magazine spaces, and 3 inches thick forward and aft of these spaces, to bow and stern; a lower and upper casemate 5 inches thick at side and 6 inches athwartships; the barbettes 8"-6"-4" thick, and the turrets 9"-7"-5".

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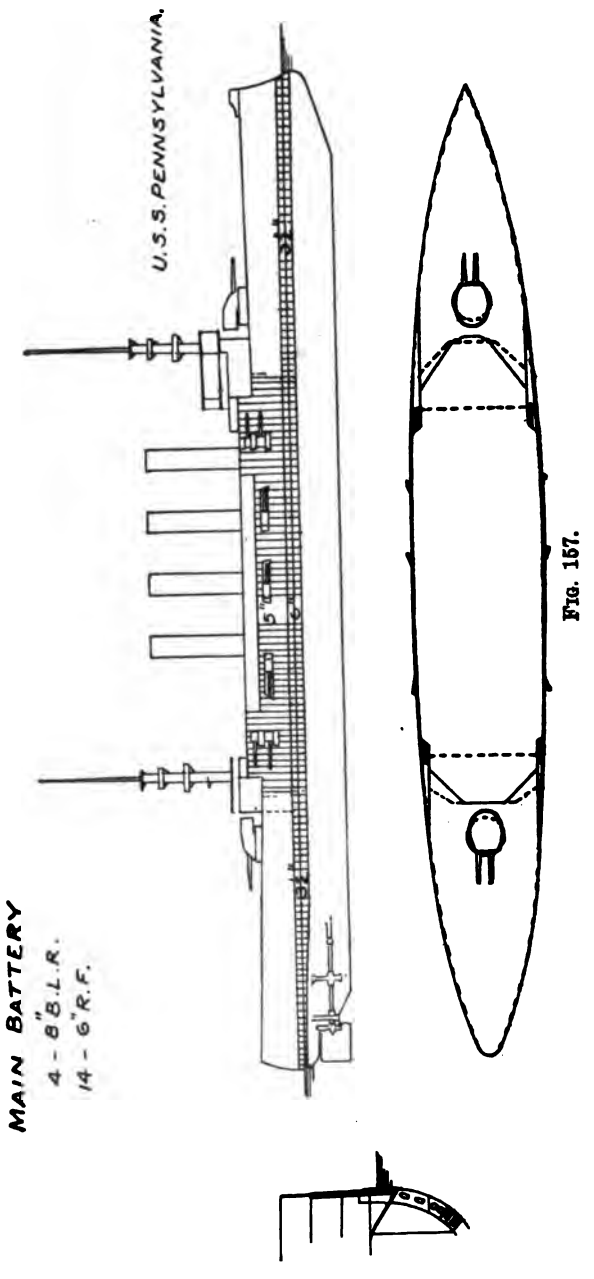

FIG. 157.

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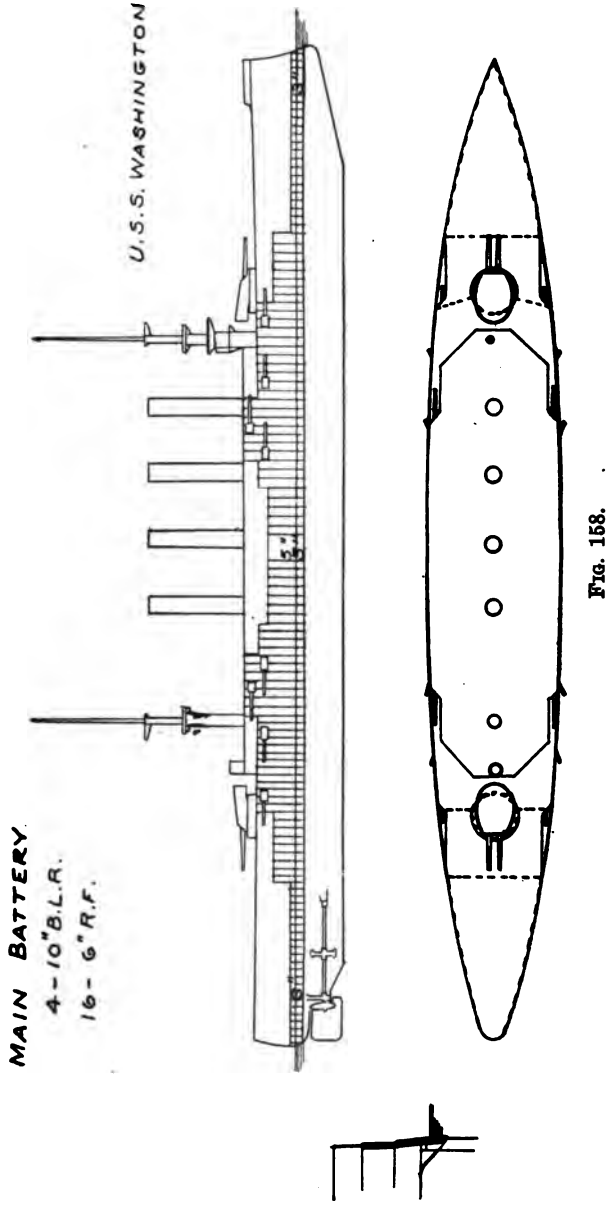

FIG. 158.

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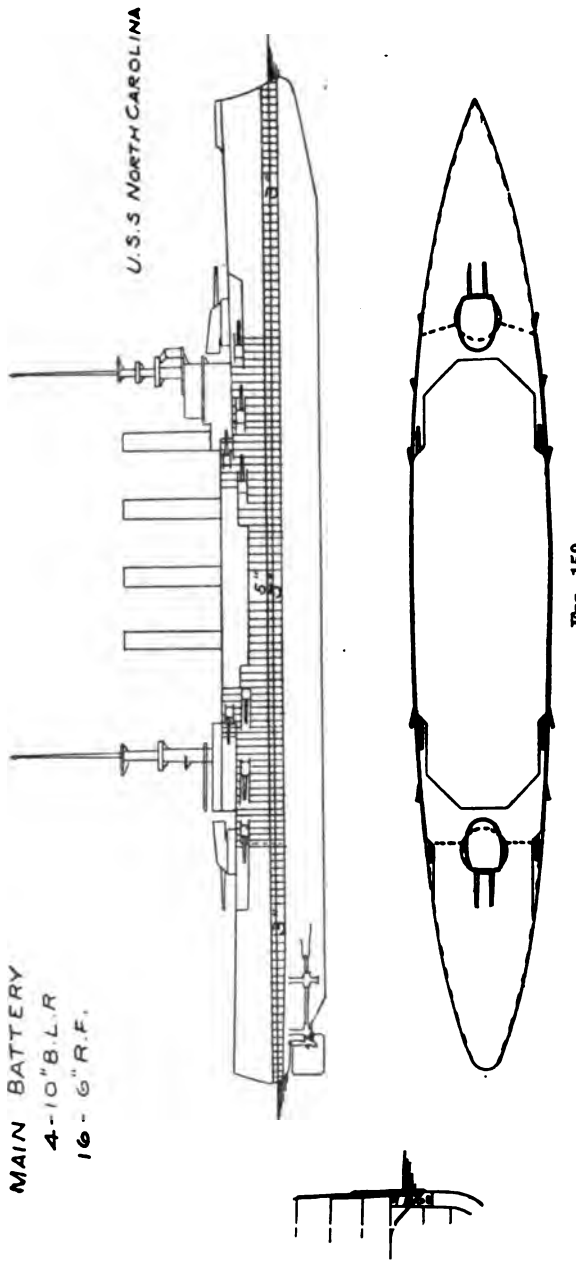

FIG. 159.

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Armor Backing and Supports.

In the early days of iron armor, such as was fitted on our early monitors, the backing was made very thick, the idea being to provide a support with proper elasticity. The thickness of backing was about equal to and sometimes greater than the thickness of armor.

Modern plates prove to offer the greatest resistance when provided with a rigid support, so that wood backing has been reduced to a thickness of 3 or 3½ inches, sufficient to form a bed for the back of the plate and to permit any irregularities of manufacture of plate to be taken up on the backing and still get an even bearing over the whole surface of the plate.

In our earlier ships, the skin behind armor was in two thicknesses, one thickness acting as butt and seam straps for the other. In recent ships this has been changed to one thickness, fitted with butt straps on inside and continuous seam straps on outside.

The earlier barbettes were "supported" by an entire cylindrical structure, but in the later ships, are supported by the resistance offered by their circular shape, the fastenings at the decks through which they pass, and the interior backing rings.

Behind armor, in spaces where the crew would be called upon to be in action, mantlet plates fastened to the inside of frames by slot-headed screws, are fitted to prevent rivet and bolt heads from flying when the armor is struck.

Armor Bolts.

The earliest form of armor was fastened by through bolts with conical countersunk heads flush on outer surface. When face-hardened armor appeared, the through holes were found to lead to cracks when struck, so that all bolts are now screwed into the back of the plate. One bolt is fitted to every five square feet. This is done so that even if the plate is badly cracked, fragments will not fall off.

The form of armor bolt and washer has undergone minor changes in the U. S. Service, but the latest form is shown in Fig. 160.

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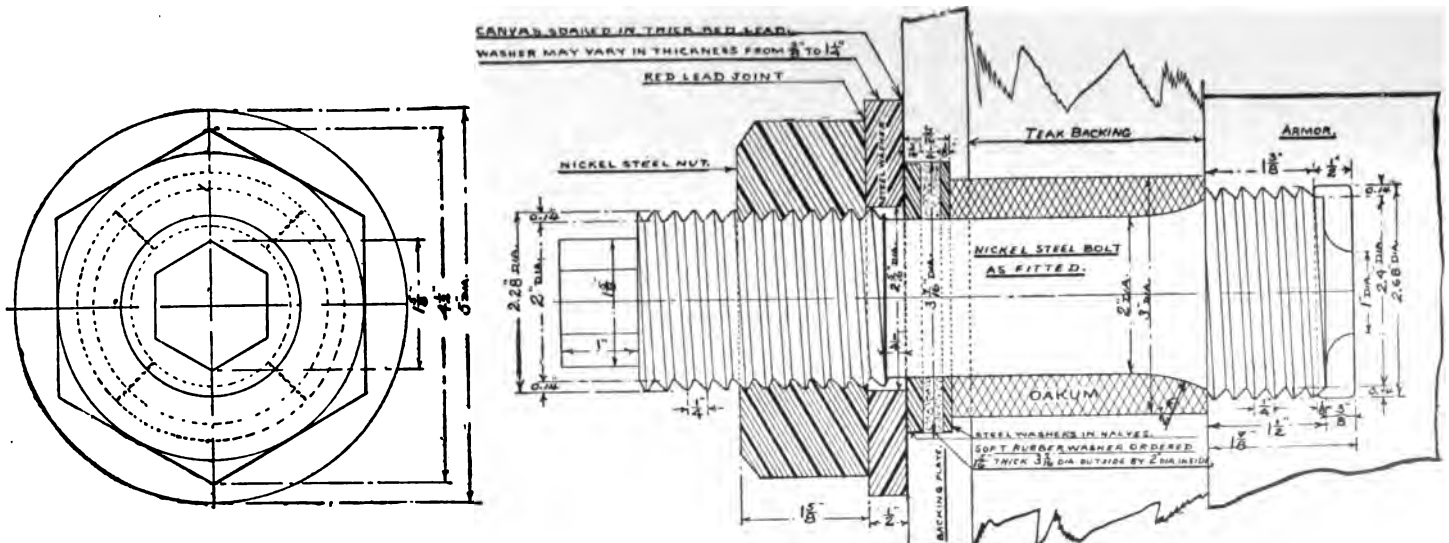

FIG. 160.—SIDE ARMOR BOLT.

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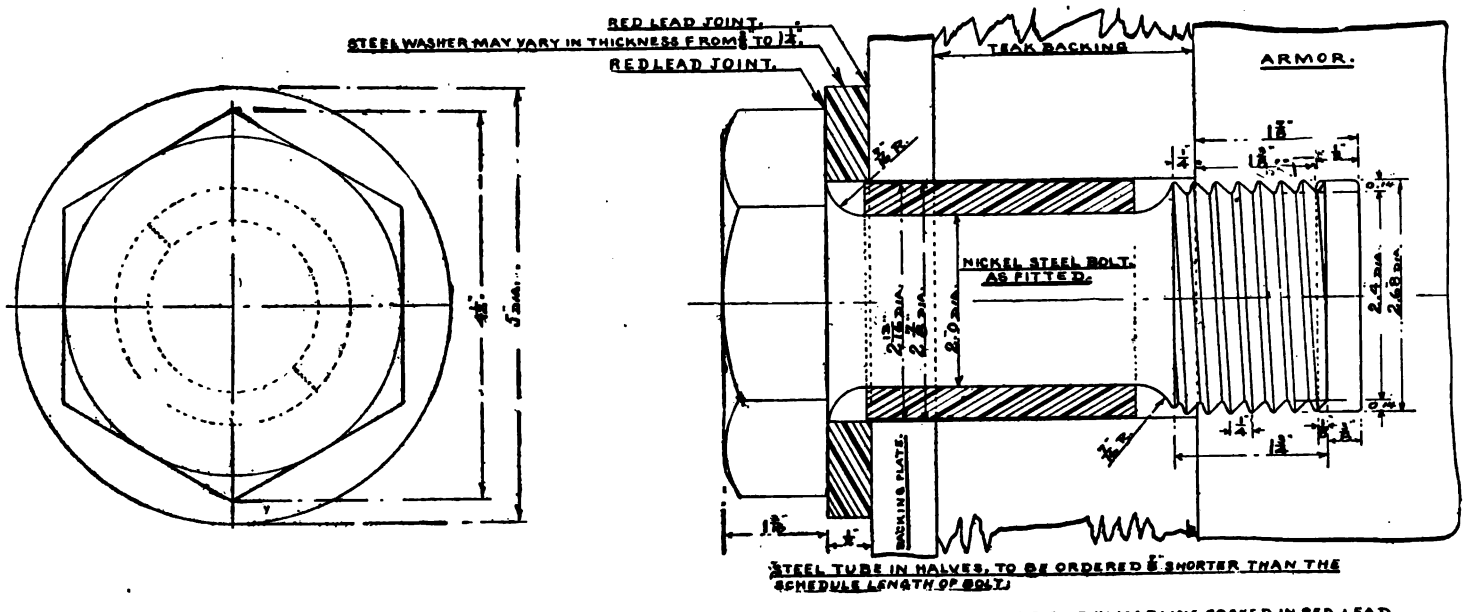
RED LEAD JOINT.
STEEL WASHER MAY VARY IN THICKNESS FROM 1/8 TO 1/2.
RED LEAD JOINT.
TEAK BACKING
ARMOR.
NICKEL STEEL BOLT AS FITTED.
BACKING PLATE.
STEEL TUBE IN HALVES, TO BE ORDERED 1/8" SHORTER THAN THE SCHEDULE LENGTH OF BOLT.
TO HOLD TUBE IN PLACE WRAP BOLT IN MARLINE SOAKED IN RED LEAD.

FIG. 161.—TURRET ARMOR BOLT.

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The shank of the bolt is slightly less in diameter than bottom of thread. This is done to prevent breaking under the thread.

The form of thread has been carefully considered. A counterbore is made in the backing plate, in which, for purposes of watertightness, are fitted, as shown, *1st*, steel washers in halves; *2d*, rubber washers; *3d*, steel split washers in halves; then a canvas gasket seated in red lead; then a plate washer; then the nut.

The type with head, shown in Fig. 161, is that used in barbettes and turrets where the space is limited, and in the side and athwartship armor above gun deck.

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CHAPTER XXI.

RESISTANCE AND MODEL TANK.

One of the most important functions of the naval architect is the determination of the underwater form of the vessel and of the horsepower necessary to obtain a given speed for a vessel.

The question of resistance and propulsion is treated at some length in Chapter XIII of Barton's Naval Engines, and, to prevent duplication, the subject of that chapter will not be discussed here.

It should be noted, however, that the most modern method of obtaining the horsepower required, and the one now used by the U. S. Service, is the *model tank* method, where the resistance of a small model of the ship is determined by towing in a tank, and the resistance of the full-sized ship determined therefrom by means of Froude's Law. (See Barton's Naval Engines, page 296.)

Without going into technical details, it may be said that the models used are usually made of wood, being cut by machinery to approximate shape, and finished by hand to exactly reproduce the ship's form. The models are 20 feet long; they are ballasted by weights or shot to any desired waterline.

The tank in which the models are towed is located at the Navy Yard, Washington, D. C., is 470 ft. long, 42 ft. 8 in. wide, and 14 ft. 8 in. deep.

The towing and recording apparatus used in resistance work is fitted to tow the model steadily at any desired speed, and to record the speed and the corresponding resistance. There are many practical difficulties in the way of obtaining accurate results, and to secure reliable data, there is needed refined apparatus and great care and skill in handling it.

Supposing all difficulties overcome, we can plot the results of towing experiments upon a model in the shape of a curve such as *AAA* in Fig. 162 showing the resistance of the model plotted upon

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speeds as abscissae. This curve represents the total resistance, made up, as we know, of skin resistance, eddy resistance, and wave resistance.

We also know that the latter two alone (eddy resistance and wave resistance), constituting the residuary resistance, follow the Law of Comparison.

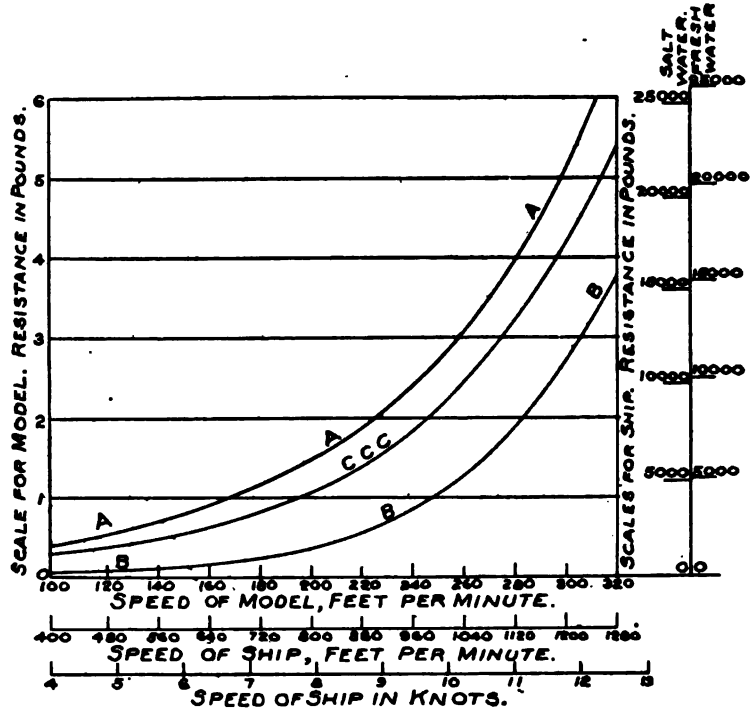

FIG. 162.

The first step, then, is to deduct from the total resistance the skin friction, which is calculated. Setting down the skin friction from the curves *AAA* in Fig. 162, we obtain the curve *BBB*, representing the residuary resistance of the model. Now we know from the Law of Comparison that this curve also represents the residuary resistance of the ship, provided the scales of speed and resistance are suitably changed.

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In the case shown by Fig. 162, the model was one-sixteenth the size of the ship; hence corresponding speeds of the ship and model are in the ratio $\sqrt{16}: 1 = 4: 1$, and residuary resistances at corresponding speeds are in the ratio $16^3: 1 = 4096: 1$.

Drawing in the scales for the ship as shown, the curve *BBB* represents the residuary resistance of the ship in either fresh or salt water, according to the scale used.

(Salt-water resistance) = 1.026 (fresh water resistance).

It is now necessary to calculate the skin resistance of the ship, and set it up above *BBB* to obtain the curve *CCC*, which represents the total resistance of the ship.

The curves of Fig. 162 are those of *H. M. S. Greyhound*, given by Froude. The actual curve determined by towing experiments upon the ship has been shown to give very close agreement with the curve *CCC* just described.

In accurate tank work, the skin resistance of a model should always be deduced from direct experiments upon plane surfaces of the same length and area and nature as the model surface. This is because an error, small in the case of model, becomes much amplified in proceding to the full-sized ship.

It is customary in the U. S. Naval Model Tank to determine five resistance curves, each extending somewhat beyond the maximum speed of the vessel. These curves are as follows:

No. 1. With the model at a displacement corresponding to the designed normal displacement of the ship and at the designed trim of the ship.

No. 2. With the model as in No. 1, except the trim is changed 4 inches by the head.

No. 3. With the model as in No. 1, except the trim is changed 4 inches by the stern.

No. 4. With the model as in No. 1, except that it is 10 per cent lighter.

No. 5. With the model as in No. 1, except that it is 10 per cent heavier.

Transactions of the Society of Naval Architects and Marine Engineers, Vol. 8, Plate 74, shows these five curves for a model representing the *U. S. S. Yorktown*. The displacement of this

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vessel, corresponding, is 1680 tons, and the designed trim 2 ft. 1½ in. by the stern. The maximum speed of the *Yorktown,* when tried at 1680 tons, was 16.7 knots. The corresponding speed of the model is 4.93 knots. The curves are generally carried higher in proportion to the designed speed of the vessel than is necessary.

Our battleships, on account of the necessity for giving them shallow draft and rather full forms, are essentially harder to drive than the deeper foreign battleships of about the same displacement. Speed can be obtained by increase of length, but great length is peculiarly objectionable in a battleship, from nearly every point of view except that of the maximum speed, involving, as it does, on a given displacement, heavier and more cumbrous rudder gear for the same maneuvering capacity, a larger target, a greater weight of hull for the same strength, a greater weight of armor for the same percentage of protected area, and usually somewhat greater power at the usual cruising speed of 10 knots.

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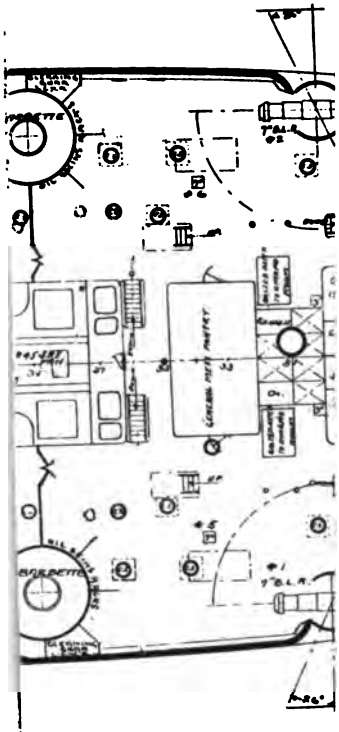

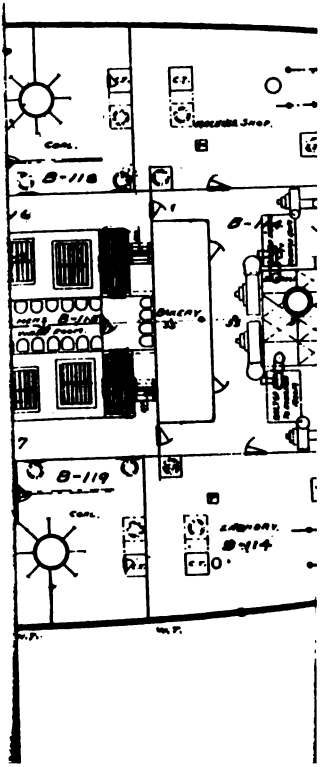

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